COVER BY RON BLALOCK

2 Putting people into armor development

Robert W. Bauer

The life cycle system management model used by the Army in developing major new weapons requires that logistics, personnel, and training subsystems be developed simultaneously with hardware. To better understand the systems integration process, the Army Research Institute studied the development of the M1 tank. Revealing some important discrepancies between theory and practice in applying the model, ARI's research suggests that alternative procedures might more effectively accommodate logistics, manpower, and training issues in weapon systems development.

---

10 Are other acquisition strategies superior to the P³I approach?

Frederick P. Biery

Defense policymakers have been searching for ways to reform procurement strategy in an effort to arrest the time-cost spiral that has come to characterize weapon system development. One approach that has gained broad support is preplanned product improvement, or P³I. This article, based on an analysis of existing modification programs, suggests that P³I is not likely to meet expectations. The author proposes a combination of procurement strategies, such as increased competition and short-range preplanning, as a more workable alternative.

---

16 What are the incentives in incentive contracts?

Dan C. Boger,
Carl R. Jones
and
Kevin C. Sontheimer

In the early 1960s the Department of Defense increased its use of incentive contracts in an effort to encourage contractors to control the costs of procurement contracts. But a model described in this article demonstrates that certain combinations of cost-sharing and incentive fee proposals can actually create incentives for cost growth. In addition, the model offers a quantitative method for determining the amount by which a cost-sharing ratio should be increased in order to avoid incentives for the contractor to incur convenience costs.

---

23 Property rights and the cost growth of weapon systems

Harold J. Brumm Jr.

The rising costs of weapon system procurements have been the subject of intense debate and scrutiny for many years. Attempts to bring these costs under control, however, have been less than successful. This article suggests that the difficulty may derive in part from inadequate attention to the property rights structure within the Department of Defense. That structure, the author argues, exerts great influence on organizational behavior and is critical to understanding the motivation of decisionmakers within DoD.

The *Defense Management Journal* is a quarterly publication of the Office of the Assistant Secretary of Defense (Manpower, Reserve Affairs and Logistics). As a forum for the interchange of ideas, the *DMJ* publishes articles on current defense policies and on methods for improving defense management. Unless otherwise stated, the of the Department of Defense or any of its elements.

Address all correspondence to: Editor, *Defense Management Journal*, OASD (MRA&L), Cameron Station, Alexandria, VA 22314. You can call *DMJ* at (703) 325-0340 or AUTOVON 221-0340.

To subscribe, Army and Air Force personnel should forward DA

28 **A clear, simple guide to weapon system troubleshooting**

Barry S. Cossel and Stephen H. Waters

As weapon systems grow in complexity, maintaining them increasingly becomes a job for skilled technicians. Unfortunately, experienced, highly trained maintenance personnel are in short supply. In developing troubleshooting procedures for the U.S. Roland program, logistics engineers at Boeing devised an approach that is quick, easy to use, and cost-effective. As described in this article, the approach allows technicians at all skill levels and with varying degrees of system knowledge to rapidly troubleshoot a complex system without extensive training.

34 **Performance-based monetery rewards can boost individual productivity**

E. Chandler Shumate, Steven L. Dockstader, and Delbert M. Neboker

In 1975 the Navy Personnel Research and Development Center began a series of studies dealing with motivational techniques designed to enhance worker productivity. Researchers subsequently found that one technique, a performance-contingent reward system, led to significant productivity improvements among key entry operators at the Long Beach and Mare Island Naval Shipyards. In this article, the authors describe the manner in which the studies were conducted and highlight various data reflecting the productivity achievements.

42 **Sharing human intelligence through a computer network**

Robert J. Knez

The use of computers today extends to a mind-boggling variety of applications, ranging from information retrieval and electronic mail to word processing and other office automation services. Here the author suggests yet another far-reaching application: a computer time-sharing network to promote the cross-fertilization of ideas among managerial subscribers from many disciplines. Known as Consultants Anonymous, the proposed network could be used by project planners, for example, who are seeking to verify the completeness of activity lists or the correctness of an event sequence.

Inside back cover: calendar

cations requisitioning channels. Navy and Marine Corps personnel should submit requests to Headquarters, Naval Material Command, MAT OOD, Crystal Plaza 5, Washington, DC 20360. Nonfederal employees and organizations may subscribe at $11.00 annually through the Superintendent of Documents, U.S. Government Printing Office.

Putting people into armor development

By ROBERT W. BAUER

According to the author, research on the M1 tank suggests that the Army's life cycle management model is unrealistic in its expectation that training and other requirements can be developed simultaneously with hardware.

In 1979 and 1980, the U.S. Army Research Institute for the Behavioral and Social Sciences initiated audit traces of several important Army development projects. The goal of the audits was to gain a better understanding of the factors involved in integrating people into new weapon systems developments. With the cooperation of the U.S. Army Training and Doctrine Command's system manager for the M1 tank (then the XM1), ARI selected that system for examination because it exemplified a new approach to development, placing much more responsibility on the contractor than in the past, and also because it was a highly visible major system. The choice may also have been influenced by the fact that the M1 is one of the more successful recent Army developments. While examining the lessons learned and presented here, it is important to note the overall success of the M1 development.[1]

In theory, the life cycle system management model used in developing the M1 is event-driven in accordance with regulations and acquisition guidance: earlier milestones must be met before moving on to later milestones. In reality, the program was time-driven by system performance requirements and cost and schedule constraints. The highest levels of management in the Department of the Army, the Department of Defense, the Office of Management and Budget, and Congress concentrated on performance, cost, and schedule as the most critical measures of program success, and Army acquisition managers responded in kind.

The audit trace of personnel and training subsystems development indicated that in the effort to keep the program on schedule and to contain costs, "people" development milestones were sometimes checked off when in fact they were not completed. People-related development lagged behind materiel from the time of the decision to omit the integrated logistic support package from the advanced development contracts for demonstration and validation. As the project manager for the XM1 noted, "This decision to omit integrated logistics support resulted in logistical support development lagging development of the tank by one phase at the time of full-scale engineering development contract award."[2]

Postponement meant that an integrated logistic support package could be prepared during full-scale engineering development for only the surviving contender in the competition, thereby saving time; nonetheless the lag persisted. For example, the final qualitative and quantitative personnel requirements information and the final military occupational skill decisions, which were checked off on schedule, were actually delayed until after initial production. Delays in hardware development similar to these delays in logistics, personnel, and training events would have been unacceptable.

Three assumptions guided ARI's audit trace:

- The life cycle system management model is de-

[1] *Most of the data and conclusions in this article are taken from J. J. Kane,* Personnel and Training Subsystem Integration in an Armor System, *Research Report 1303 (Washington, DC: U.S. Army Research Institute for the Behavioral and So-*

[2] *Letter from Colonel H. J. Velort, Deputy Project Manager, XM1, to Major General Alan A. Nord, USA, January 26, 1979, subject: LEA XM1 ILS Program Review (Draft), 2 January 1979: Summary of XM1 PMO Staff Comments, p. 1 of*

• The model is intended to provide accurate, timely data to decisionmakers in the Army, DoD, the Office of the President, and the Congress.

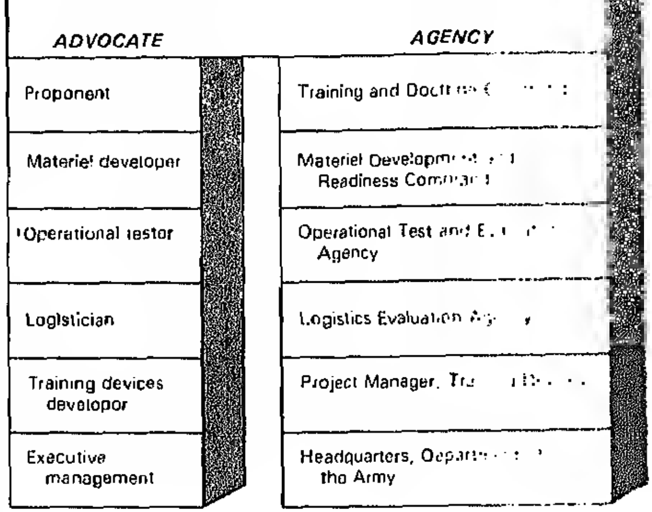
• Deviations from the model's procedures and the effects of those deviations would be of interest to project and system managers.

The scope of the audit trace included only the period of development from milestone 0 to Army System Acquisition Review Council milestone III and did not include all of the production and deployment phase.

The approach used in analyzing the case was an advocacy method designed to simulate organizational interactions. The organizations involved in the M1 development were divided into six groups, each representing a different organizational perspective (see Figure 1). One researcher or advocate traced the activity of each group and represented its perspective and experience.

ARI also assembled a board of highly experienced senior scientists to role play upper-level Army and DoD management and to represent the total systems viewpoint. This board received briefings from the advocates, reviewed the overall progress of the case study, and provided guidance to the research team.

Interactions during the M1 development



The model

The life cycle system management model comprises five phases (see Figure 2):

• The first phase involves approval of the mission element need statement and now also includes appointment of a system manager from the Army's Training and Doctrine Command (appointed later in M1 development).

• The second phase is an exploration and identification of alternative system concepts, including those for logistics, personnel, and training. Toward the end of this phase, the decision on demonstration and validation is made, a project manager is appointed, and a draft decision coordinating paper is approved by the Secretary of Defense. When this paper was approved for the XM1 in January 1973, it gave the newly appointed project manager seven years from that date to begin production.

• The third phase for the XM1, demonstration and validation (formerly called advanced development), included competitive contract awards to General Motors Corporation and Chrysler Corporation for production of prototype weapons, which were tested later that same year. The third phase also normally includes approval of a training device requirement and a required operational capability.

• The fourth phase, full-scale engineering development, consists of additional development and tests and Army and Defense System Acquisition Review Councils II. For the XM1, the contract award to Chrysler initiated this phase, which also included development test II and operational test II, final personnel requirements information, the MOS decision, and logistic support analysis.

• The fifth phase, production and deployment decision, included ASARC III and DSARC III. In the case of the XM1, it was concurrent with a decision to enter low-rate initial production.

M1 personnel and training subsystems

As the project manager pointed out later, the XM1 development represented a new approach. "In the past we just sort of fitted the pieces together. There was no real, from-the-ground-up thought process." Traditionally, he went on to say, "Development has been dominated by an in-house philosophy that rejected the idea that industry should have a part in this."[1] However, the Main Battle Tank Task Force, which convened at Fort Knox, Kentucky, in February 1972, recognized the need for increased contractor responsibility for system development and integration. The task force identified 11 desired characteristics and listed them in order of decreasing

[1] *Quoted in Eric C. Ludvigsen, "XM1 Fa... Strong Impact on Future Ground Forces," Army M... February 1976, pp. 32–35.*

compared to the current Life Cycle System Management Model

PHASE	CURRENT STANDARD	M1 DEVELOPMENT
I	Program initiation (milestone 0)	Concept formulation
II	Exploration of alternative system concepts	
	Demonstration and validation decision	
III	Demonstration and validation	Advanced development • Contract award and test • Planning
	Full-scale engineering development decision	Full-scale engineering development decision
IV	Full-scale engineering development	Full-scale engineering and development • Contract award and test • Planning
V	Production and deployment	Production decision

priority for the advanced development phase. Among the characteristics were crew survivability (third in priority) and human engineering (ninth).

In mid-1975, the Tank Special Study Group, organized at Fort Knox by TRADOC's commanding general, elevated crew survivability to first priority. This group placed additional emphasis on system characteristics involving human performance, assigning second priority to surveillance and target acquisition performance, for example; third priority to first- and second-round hit probability; and twelfth priority to human factors. Its list numbered 19 characteristics.

To address human factors in the engineering development phase, Chrysler established both a human factors engineering program and an engineering-system safety group. The Army's Human Engineering Laboratories and its Medical Research and Development Command regarded this contractor effort as very successful.[4] They concluded that in spite of some deficiencies, the design of the XM1 was probably the best from a human factors standpoint of any American fighting vehicle in the current inventory.

Logistics problems. The logistics arena fared less well. Advanced development contracts for the XM1 did not require development of integrated logistic support packages for evaluation at development and operational test I. The rationale was that two such packages in the competitive phase would be redundant and that cost savings could therefore be realized by waiting until full-scale engineering development.

To further reduce costs, the Army decided to require during engineering development neither a full logistic support analysis nor a logistic support analysis record, intended to identify and quantify logistic support requirements for materiel development. As a result, requirements for integrated logistic support were not met and the delivery of such support, including personnel and training packages, fell back by one phase.

The gap between hardware development and logistic support development widened further due to the project manager's decision to permit extensive contractor involvement in maintenance during operational test II. Since contractor personnel did much of the maintenance, the data available on maintenance performed by soldiers were very limited. The director of supply and maintenance for the Army's Deputy Chief of Staff for Logistics expressed his concern, and in 1979, that office directed its Logistics Evaluation Agency to do an interim assessment in preparation for the low-rate initial production decision.

The Deputy Chiefs of Staff for both Personnel and Logistics were reluctant to become involved early in the development because the Army had not funded an integrated logistics support package as part of the initial XM1 program. Also, they were aware that the hardware concept was rapidly changing and that data on soldier performance were lacking.

Numerous later problems and delays associated with

[4] *U.S. Army Human Engineering Laboratories and Medical Research and Development Command, "Human Factors Engineering Analysis (HFEA) for XM1 Tank System ASARC I," Aberdeen Proving Ground, Md., January 10, 1979.*

analysis and review during full-scale engineering development. Therefore, it is doubtful that the Army actually saved costs by these early reductions.

Rather, these may have been costly decisions, a view supported by the Tank Forces Management Group, whose report criticized tank project managers for delaying integrated logistics support planning: "This strategy makes it impossible to develop complete logistic and training support packages for operational test II," and as a result, "delays a full production decision, an expensive proposition. Thus, the front-end cost savings achieved by delaying integrated logistic support planning are lost when the effects of that strategy cause production delays later in the program."[5]

In retrospect, it is easy to see that greater interest in integrated logistics support early in the program would have made managers aware—before 1979—that a 1500-horsepower engine in the M1 (whether turbine or diesel) versus a 750-horsepower engine in the M60A1 would require more fuel trucks and more truck drivers. Some of the impact of new components on maintenance personnel could also have been anticipated.

Manpower requirements. As in the case of logistics, difficulties in identifying manpower requirements actually derived from several earlier problems and decisions. The first maintenance test sets, for example, which were evaluated in a special maintenance evaluation in February and April 1978, had severe reliability problems; consequently, the troubleshooting manuals based on their use were invalid. Due in part to this problem, annual maintenance man-hours were obtained in neither the evaluative physical teardown nor in operational test II carried out in 1978–1979, when contractor personnel did much of the maintenance. Failure to collect these data resulted in very speculative annual maintenance man-hour estimates based largely upon M60A1 experience; delays in final MOS decisions thus persisted into 1979.

The failure to gather maintenance data based on soldier experience in operational test II in turn affected the qualitative and quantitative personnel requirements information document, which the Training and Doctrine Command was to have submitted to Army headquarters in September 1977. Subsequently changed to August 1978, that submission date was not met either, all affected parties. Both the Ordnance and Chemical Center and School and the Logistics Center, for instance, found the information in it insufficient for their purposes.[6]

In July 1977, the Military Personnel Center initiated a requirement for an initial recruit and training plan for systems acquisitions. The plan for the XM1, which had been selected as a test case for the requirement, was published in October 1977 and revised in March 1978. Though the project manager's office admitted that annual maintenance man-hour data on the XM1 were insufficient, it urged approval of a final personnel requirements document in 1979 so that the XM1 program could be kept on schedule. That final report was based upon M60A1 data, but the 1979 update of the initial recruit and training plan acknowledged that in fact "logistic supportability, ammunition and fuel, together with proposed changes in support doctrine, will necessitate a large manpower increase."[7]

Training requirements. Problems related to training surfaced as well. In preparing for ASARC milestone III, the Logistics Evaluation Agency did an interim logistics assessment of the XM1 which identified three critical skills: fire control computer repairman, vehicle mechanic, and turbine engine repairman. The agency concluded that additional duties for individuals in the first and second groups would be too much for these personnel to handle and, while noting favorably the XM1 system manager's efforts in logistic support development, training, and logistic test evaluation, also commented on the complete lack of diagnostic test sets and the resulting adverse impact on maintenance training programs. The same interim assessment recorded the significant lag in training devices and the failure to validate the training manuals.

After reviewing the Logistics Evaluation Agency position and the logistics readiness review prepared by the Materiel Development and Readiness Command, the

---

[5] *Lieutenant General James Kalergis, USA (Ret.), et al.,* A Program for Maximum Effectiveness . . . Tank Weapon System Management, *Tank Forces Management Group, The Pentagon, Washington, DC, Undated (ca. August 1977), p.V–17.*

[6] *U.S. Army Ordnance and Chemical Center and School Memorandum, March 30, 1978, subject: Amended Qualitative and Quantitative Personnel Requirements Information (AQQPRI) for XM1 Tank, Combat, Full Tracked, NETP No. TAR-7; Logistics Center Memorandum LOGC May 3, 1978, subject: Amended Qualitative and Quantitative Personnel Requirements Information (AQQPRI) for XM1 Tank, Combat, Full Tracked, NETP No. TAR-7.*

[7] *Military Personnel Center, "Military Personnel Center Initial Recruit and Training Plan for XM1 Tank System (U)," Alexandria, VA, May 31, 1979 (Updated June 20, 1979) (CONFIDENTIAL). Tab B.*

istics Evaluation Agency noted that introducing ning devices after fielding would create "turmoil." ugh revised materiel need documents had called for current development of tank and training devices testing of the training devices during operational II, the project manager's office asserted that "it never planned to have prototype training devices lable for development and operational test II" and stated that "the XM1 training devices, while highly rable, are not essential to operational test III in) or fielding in 1981."[8]

dy in contrasting views

he history of the development of XM1 training de- requirements and training devices is a study in rasting views within TRADOC. In the concept phases Tank Special Study Group took the position that training devices had to be developed concurrently the XM1. It called for delivery of production models both the driver trainer and conduct-of-fire trainer re development and operational test II; evaluation nese two devices to proceed concurrently with that , and delivery of the organizational, direct support- eral support, and full crew devices before devel- ent and operational test III.[9]

he original XM1 master schedule called for TRA- C to submit training device requirements to Army dquarters in May 1974. Although the command was able to achieve agreement by that date, the Army's ior School did forward proposed requirements in 1974, which included a tank driver trainer, turret ier, and a turret repairman maintenance trainer. vever, TRADOC's deputy for training wanted more vative thinking that would employ the latest in sim- ion technology. He was particularly interested in -in electronic and computer-connected devices which ld give personnel access to computer-generated im- y simulation in a very physically constrained en- nment.

late 1974, the XM1 program manager urged the ning and Doctrine Command to come to an ex- tious decision on the XM1 requirements. Following command's reply that the decision would be delayed

engineering development. He also needed Department of the Army approval by December 15, 1975, to meet FY 1977 budget deadlines. The Training and Doctrine Command did not respond in time to meet either deadline.

In April 1976, TRADOC reached agreement with the Materiel Command to fund training device development. TRADOC also undertook several studies in 1976 to analyze device feasibility and effectiveness. When the demonstration and validation phase on the XM1 ended in July of that year, development work under the letter of agreement was still in progress, and it became obvious that the training devices would not be available for XM1 operational test II. Instead, it was proposed that device prototypes be ready for training personnel at operational test III. TRADOC developed a set of draft training device requirements and in July 1977 submitted them to Army headquarters, which approved them in late 1977.

At this point, the training device requirements were approximately three and one-half years tate. The report from the Tank Forces Management Group cited fragmented responsibility for tank training devices and TRADOC's failure to submit timely requirements information as contributing factors.[10] Because of these delays, the first conduct-of-fire trainer was not scheduled for delivery until a year after XM1 fielding, and the first one-station unit trainer would not be available until at least 3 years after the start of institutional training.

In theory, the Training and Doctrine Command, as the proponent, is the driving force behind the Army's system acquisition cycle. New programs are initiated based on its continuing analysis of mission needs, and programs are continued based on its refinement of requirements and evaluation of effectiveness. However, once a program has begun, the Materiel Development and Readiness Command's project manager is in charge, and that command's hardware development paces the schedule.

The project manager is not always able to respond to TRADOC's problems. For example, the XM1 manager could not provide enough tank prototypes to support the development and validation of training materials and devices. When a twetfth tank could not be built for operational test II, the requirement for validation of the integrated technical documentation and

etter from Colonel H. J. Vetort, op. cit.

'ank Special Study Group, User Review and Analysis of 1 Tank Requirements Documentation, *Vol. III, "Re- ments Review (U)," U.S. Army Armor Center, Fort Knox, June 30, 1975, p. 12–5.*

[10] *Lieutenant General James Kalergis, USA (Ret.), et al.,* op. cit., *p.* V–19.

out the devices.

Is concurrent development possible?

Perhaps concurrent development of hardware and training materials and devices is simply not possible. Project managers for both the XM1 and the fighting vehicle systems have recently stated that they believe some incoordination is inevitable. A collapsed development schedule, such as the 7-year XM1 schedule, creates an environment of rapid change. Development and operational tests often proceed simultaneously; engineering changes in hardware take place even during user testing; and user test crews and maintainers are introduced to new components frequently. Even if a prototype could be delivered on time, evaluating a training device might prove difficult under such circumstances. Training manuals are also usually undergoing rapid change. The new equipment training experience is sometimes used to correct and update preliminary manuals and to reconsider training requirements and innovations as well.

In addition, during XM1 development the newly organized Training and Doctrine Command was introducing innovative ideas and practices. The system manager concept, skill performance aids, high technology training devices, and cost and training effectiveness analyses were all among them. In part, the command's difficulties in developing training device and personnel requirements were due to internal reorganizational efforts—ironically, undertaken to improve consideration of personnel and training factors.

The XM1 project manager's drive to achieve schedule, cost, and performance goals, whether or not a milestone was slipped, are readily understandable in the historic and economic context of major weapon system development. Scheduling delays of the materiel system were almost certain to involve increased costs and unfavorable attention from the U.S. General Accounting Office and the executive department, with associated risks to the whole program.

Clearly, the divergence between the theory and the reality of the life cycle system management model is too great in the personnel and training areas. In a recent report for the Army Materiel Systems Analysis Agency, General Walter T. Kerwin, who served as chairman of the council for ASARC milestones II and III, stated that the model needs more discipline with respect to manpower, personnel, training, and logistics issues. "Initial operational capabilities and compression of the that every time a waiver is granted or integrated logistic support is deferred, the manpower, personnel, training, and logistics issues suffer."[11]

The current model requires that training device requirements be passed on to the device developer at a stage where there are still very high risks of significant design changes. Risk of training device invalidation is necessary if the device is to be available when the weapon is first issued. The XM1 maintenance diagnostic simulators illustrate the risks posed. When these test sets did not perform well in development test and operational test II, a nearly complete set of maintenance trainers was invalidated.

As suggested earlier, delays in areas such as crew simulator training development were not attributable to changes in the XM1 design so much as to changes going on within the Training and Doctrine Command itself. That the delay of several years in crew simulator training did not cause greater concern to upper level managers of the XM1 development supports the view that the life cycle system management model is unrealistic in requiring training device development simultaneous with hardware development. If, indeed, training device requirements cannot be realistically determined prior to operational test II, then the requirement to deliver prototype devices for evaluation at system operational test II should be eliminated from the model.

A more gradual and evolutionary introduction of training during the early period of production and delivery may be in order. Though the Army's Operational Test and Evaluation Agency was designated as operational tester of the XM1 system, that agency did not have responsibility for testing training devices or training. Instead, TRADOC is designated operational training developer and tester for training devices, even though evaluation of the capability of trained personnel is part of the operational testing phase.

Alternative procedures

As an alternative to current practices, TRADOC could evaluate training systems and devices during the force development testing and experimentation. Also worth considering is a development test for training devices.

---

[11] *General Walter T. Kerwin, USA, General George S. Blanchard, USA, Erwin M. Atzinger, and Phillip E. Topper, "Man-Machine Interface—A Growing Crisis," Army Materiel Systems Analysis Agency, Aberdeen Proving Ground, MD, August 1980.*

n major systems. Moreover, assigning respon- or both developing and testing training systems ier command, such as the Deputy Chief of Staff sonnel, with the Training and Doctrine Com- s a participant, would be more consistent with cept of independent evaluation. In any case, bility for evaluation must be clearly assigned arly planning for training support development.

lition, better manpower and logistics estimates nade early in development. Areas for improve- clude communication between the project man- ffice and the logistic agencies responsible for ed logistics support development, and the tim- nitiation of support package developments in e of the Army's Deputy Chief of Staff for Lo- the Deputy Chief of Staff for Personnel, and OC. Clearly establishing responsibilities for de- ent and delivery schedules is very important. sibility for human resources development can alized in the project manager's office, as was the relatively successful development of the f target acquisition system. In that develop- deputy project manager served as focal point an resources issues.

r the compressed schedule, the time between ment and operational test II and ASARC III is iot sufficient for completing key events relating ualitative and quantitative personnel require- tegration document, basis of issue, and training on. Since those products require the data gath- ing development and operational test II, some al time for analysis and review prior to ASARC be allowed. Similarly, the time lapse between ment and operational test I and ASARC II may be increased if the intervening milestones are complished.

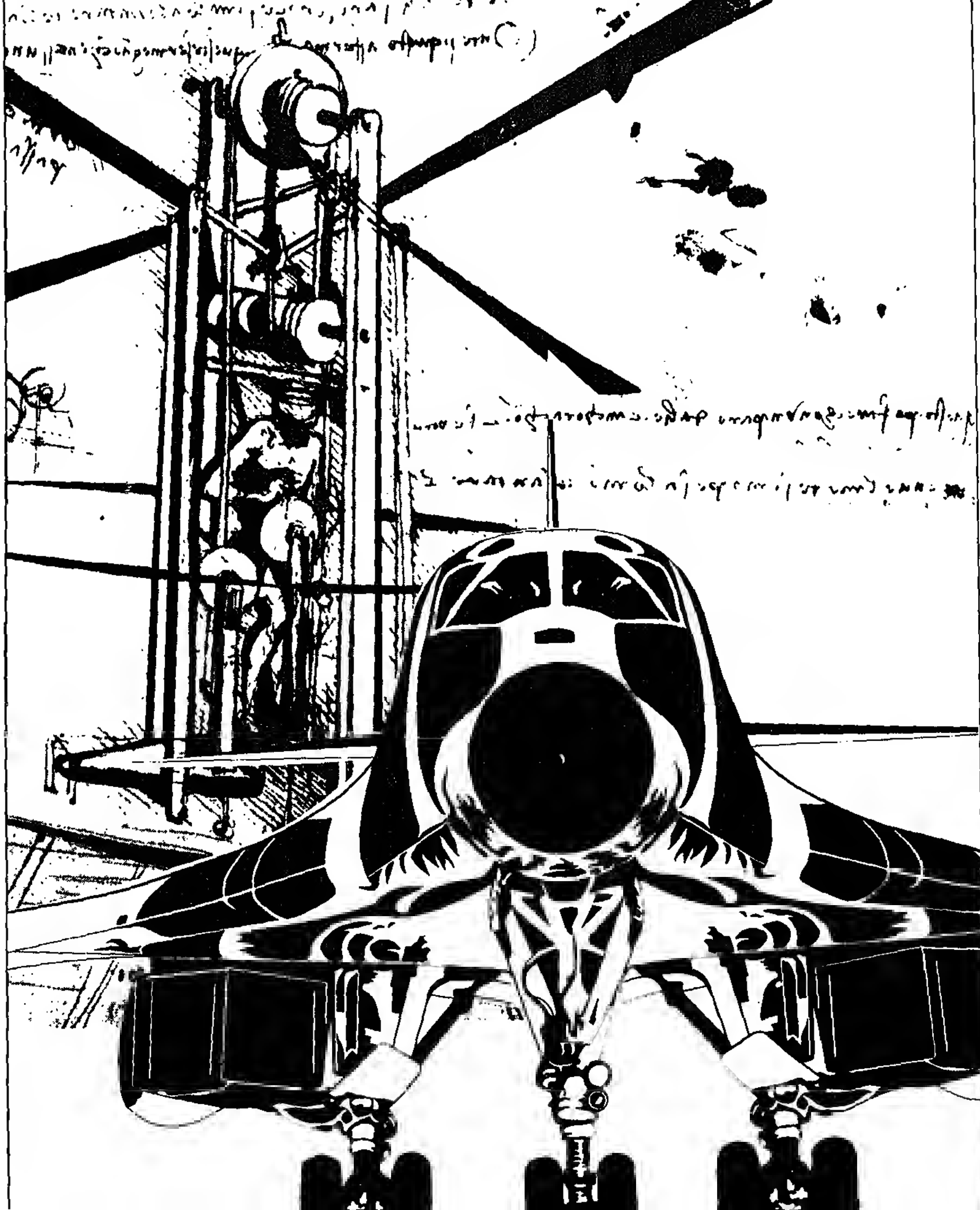
ower, personnel, and training issues need greater n and priority in both the Army and Defense Acquisition Review Council processes. The rel- nphasis upon hardware, cost, and scheduling ies shuts out personnel, training, and even lo- upport. Better articulation of the Army agen- sponsibilities, milestone (product) descrip- nd timing of deliveries will solve part of the , but not all of it. One reason for the sub- position of the human dimension in systems ion has been the relatively low priority and accorded personnel and training development A separate schedule and budget for manpower, el, and training systems could provide a vehicle levels of the Army, Department of Defense, and Congress. If documents such as the selected acquisition reviews and the Army program reviews incorporated personnel and training milestones and objectives, these would receive high-level review similar to that accorded hardware developments. The likelihood of more timely accomplishment and higher quality would be substantially increased.

The Army experience with XM1 development points up both strengths and weaknesses in the currently evolving system for manpower, personnel, and training development in a major new weapon life cycle. The Training and Doctrine Command's system manager is able to expedite the development of manpower, personnel, and training products only insofar as responsibilities are clearly allocated. To be effective, that system manager must also coordinate closely with the project manager, whose level of involvement in human resources has important consequences. In addition, the prime contractor can be required to provide human factors and training developments, but only if the contract specifications are well defined.

Integrated logistics support and manpower, personnel, and training developments are interdependent; delays in one seriously impede the other. Some time requirements of the life cycle system management model may be unrealistic. For example, a longer lag between training and training device development on the one hand, and hardware development on the other, may be unavoidable. Realistically, development and testing of training and training devices is likely to continue for some time after initial operational capability.

More reasonable and explicit recognition of people integration in the project manager's planning and budgeting, plus greater visibility for manpower, personnel, training, and logistics developments in reports to upper-level Army and Defense Department management, will do much to improve the integration of people into new Army systems. DMJ

ROBERT W. BAUER is a research psychologist with the Fort Knox, Kentucky, field unit of the U.S. Army Research Institute for the Behavioral and Social Sciences. Previously, he served in the same capacity with the U.S. Army Human Engineering Laboratories. The focus of Dr. Bauer's current work is training and human factors analysis; he is the author or co-author of some fifty publications. He holds both the Ph.D. in psychology and the Ph.B. from the University of Chicago.



Are other acquisition strategies superior to the P³I approach?

BY FREDERICK P. BIERY

Experience suggests that the answer to DoD's procurement problems may lie in a combination of techniques rather than a single-policy approach.

The escalating costs of new weapons, ever-lengthening acquisition cycles, and other worrisome trends in recent years have disturbed many defense analysts. They note that while the typical fighter aircraft of the 1950s cost $4 million in 1975 dollars, the average cost of a fighter in the 1970s, as measured in same-year dollars, had nearly tripled to $11.7 million. During the same two decades, the typical procurement cycle—the period of time between issuing a requirement for a new weapon and fielding the system—had stretched to 10 years.

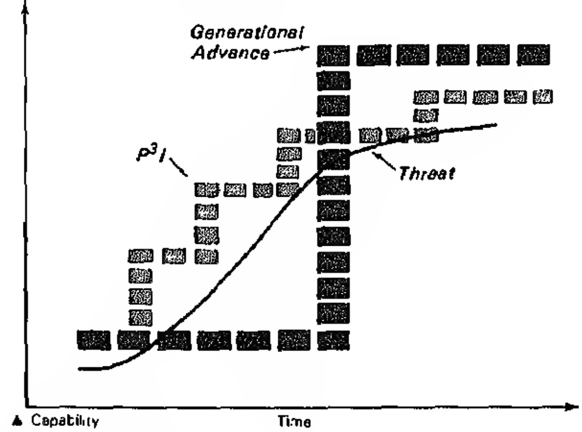
Unstable procurement budgets, which fluctuated considerably in the 1970s and rarely sustained any real increases, further aggravated weapon cost escalation. These various factors also led to the steadily rising age of U.S. military equipment. The average age of Air Force tactical aircraft, which was 3 years in 1960, had doubled by 1970, reached 8 years in 1980, and is expected to be 10 years by 1985.

Not surprisingly, defense analysts have been searching for ways to arrest these negative cost, time, and budget trends. They realize that to reduce the average age of the Air Force inventory to 5 years, for instance, DoD would have to purchase at least 600 aircraft each year. But the essence is the preplanned product improvement strategy, or P³I. It is one of the key weapon system acquisition reforms initiated by former Deputy Secretary of Defense Frank C. Carlucci and has been praised by defense analysts and industry representatives alike. General Accounting Office analysts view the concept favorably, as do congressional officials.

But while the theory has been endorsed and ensconced as policy, it has received little detailed analysis. Discussion of the concept's advantages and disadvantages continues to be abstract and theoretical, and P³I has yet to show its metal by being successfully applied to a major weapon system. To determine what benefits might realistically be expected from P³I, this article will review the theory in light of past experience in weapons modification and improvement. It will also consider other strategies that might successfully reverse recent trends in weapon systems acquisition.*

Preplanned product improvement was rapidly endorsed because it appears to offer a solution to the problems of high costs and long lead times in weapon systems procurement. It proposes to do so by systematically incorporating capability im-

* *This article draws on material from Frederick P. Biery and Mark Lorell,* Pre-Planned Product Improvement and Other



Source: American Defense Preparedness Association Proceedings, April 1980, p. 118.

provements and modifications over the course of a system's life. Rather than starting a new program to meet new needs and threats, P³I would upgrade weapons in the inventory. Modifying systems already in the inventory is currently a multimillion dollar a year activity, and programs such as the M60 tank and the F–4 fighter have undergone many modifications in their lifetimes. But those urging preplanned product improvements view it as a new and fundamentally different acquisition strategy, one quite different from current modification practices.

First, proponents characterize P³I as a strategy. It offers a coherent plan for multiple system upgrades well into the future rather than a series of ad hoc modifications proposed and implemented as the need arises. Ad hoc programs, such as the improvements made over the years to the B–52 bomber or A–7 aircraft, have not followed a systematic, lifelong improvement plan. Modifications are generally reactions to new technology, threats, or user needs, and are not part of a multiyear, multiphase improvement plan established when the system was designed.

Preplanning is the second distinguishing feature of the approach. Supporters believe that a P³I system, designed from its origins to accommodate long-term improvements, should provide significant advantages over a conventionally designed weapon system, for which modifications are not

ple) in new weapon development progra Figure 1). Reducing the technological aggr ness of weapon development programs lowers the risk of cost growth and schedul page.

Traditional, ad hoc modification progra erally take less time to complete and as a ru less than does development of a new system. ponents of preplanned improvements expec ilar results; indeed, they foresee even better r from preplanned systems. While a P³I syst likely to offer less capability and performance a new weapon development program, its a pated lower costs and faster completion time offset this disadvantage.

These hypothesized advantages are signif and clearly make P³I an attractive strategy to sue. However, the costs and benefits are uncert and important questions of feasibility and m mentation remain. For example, how should weapons designer proceed? How can prepla be incorporated into the source selection pro What kinds of systems should be selected as didates?

Partial answers to such questions can be by reviewing related experience gained under lier programs. A considerable volume of mo cation activity occurs regularly and can pro insight into the feasibility of P³I and some guid on how best to pursue this strategy. In doing analysis of P³I for the Air Force, the Rand C poration studied modification programs simila preplanned product improvement and also viewed ad hoc modification efforts. Such a sur of past efforts raises serious concerns.

Aircraft development contracts, both comme cial and military, often include growth or mod cation potential as a design goal. Aircraft design and manufacturers have every incentive to de the most flexible, easily improvable system p sible because future modification potential me longer production runs and greater eventual sal The Defense Department too has recognized th value of improvement potential. In the early 197 for example, the request for proposal for the ad vanced medium short-takeoff-and-landing tra

or technological advances with enough specificity to preplan improvements far into the future is unreasonable. Preplanning improvements to major systems is based on the premise that such anticipation is feasible; experience suggests it is not.

port listed growth potential as a contract award evaluation factor.

Surprisingly, however, a survey of all Air Force jet fighter modifications, most Navy fighter and attack aircraft programs, and several bomber modifications reveals little evidence of any P³I-like modifications. In fact, such a review indicates that rapid advances in technology, combined with changes in threat and user requirements, quickly erode any preplanned improvement potential. Only the F-5, the F-14, and the Northrop N-102 projects appear to have included elements of preplanning during the design stage. More recently, designs for the air-launched cruise missile program also contained plans to accommodate future improvements.

The Navy's experience with the F-14 program illustrates how unforeseen difficulties can undermine preplanned upgrades. In the 1960s, Navy planners were concerned that the proposed F-111B would not adequately perform the fleet air superiority mission. The service believed it needed a fighter plane quickly to replace the F-4 but knew that Congress was unlikely to fund the high-risk crash effort a new fighter development program would probably entail. So Navy designers combined F-111B subsystems then being developed, the TF-30 engine, and the AWG-9 Phoenix missile system into a new airframe. Combining these systems reduced the technical risks and provided the needed capability more rapidly than if designers had developed a wholly new system from scratch.

However, the Navy still saw a need for better subsystems and planned to gradually upgrade the F-14. The first aircraft produced was to be the F-14 with the TF-30 engine and the AWG-9 missile; later F-14Bs would use the more powerful F401 engine, which was in the early stages of development ... troduction of the F-14C, with improved avionics.

Unfortunately, developing the F-14A proved a more difficult task than expected. Because of cost growth, delays, and technical difficulties on the airframe, the TF-30 engine, and the F401 engine, the Defense Department postponed the purchase of the F-14B indefinitely. The Navy has tried unsuccessfully to reverse this decision since 1971 and therefore has not been able to realize the hoped-for benefits from anticipating future improvements. Some contend that the F-14A remains somewhat underpowered as a result.

While the F-14A illustrates the vicissitudes that can befall a weapons program, the development problems encountered in the F-14A program cannot be attributed to pursuing a development strategy similar to P³I. In fact, by choosing the TF-30 engine, a more technically mature engine than the F401, the Navy may have avoided additional problems. The decision to reduce cost, schedule, and technical risks by using the TF-30 engine, however, forced the Navy to settle permanently for an engine that planners envisioned as a transient one.

The dearth of P³I-like experience made it advisable to examine aircraft systems which have successfully undergone many ad hoc modifications to determine why they were so adaptable to being upgraded. Three such programs in the active Air Force and Navy aircraft inventories are the B-52, the F-4, and the Navy A-4 attack aircraft. However, the designers of those systems would probably not have been able to guess accurately the nature and variety of the future alterations made to their original designs; for instance:

- How could Boeing designers in the late 1940s foresee that changes in Soviet air defenses would require modifying the B-52 in the late 1960s to operate at low altitudes?

meet the Navy's requirement for a fleet air defense aircraft in the 1950s, anticipate its air-to-ground role in the mid-1960s?

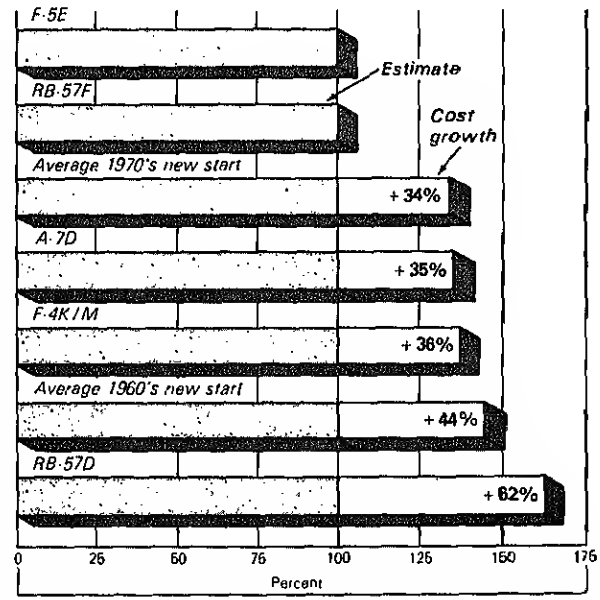
- When they built the A–4 in 1953, E. H. Heinemann and the Douglas Company set out to produce the lightest, simplest aircraft possible. They made no special provisions for incorporating new engines, larger ordnance loads, or improved avionics, yet the firm has since produced nearly twenty versions of the aircraft.

The reasons behind the long life of systems such as the A–4 seem to have more to do with luck and regularly applied good design practices than with carefully anticipating future improvements. Indeed, expecting designers to envision threat changes, mission changes, or technological advances with enough specificity to preplan improvements far into the future is unreasonable. Preplanning improvements to major systems is based on the premise that such anticipation is feasible; experience suggests it is not.

Evidence from the F–14 program and the few others that utilized preplanning does indicate that forecasting improvements over only a few years, perhaps 3 to 5, may be workable, especially when the subsystems to be incorporated into the baseline system are already in development. This building-block approach may be especially appropriate for electronic systems, and in fact the Soviet MiG and the French Mirage aircraft programs have already successfully applied a development strategy which relies on off-the-shelf subsystems combined with incremental upgrades to improve capability. Incrementalism, as this approach is sometimes called, has never specifically entailed preplanning for upgrades. However, linking incremental development strategies with very short-term preplanning is probably more viable than the grander notions involving advanced long-term product improvements.

Earlier programs also indicate that any preplanning involves risk. As in the case of the F–14, planned-for improvements may not be funded, and the service may have to settle permanently for what was initially thought to be a transitional system. The additional time and money spent during a sys-

Figure 2. Modification efforts occasionally exhibit a greater percentage of cost growth than do new programs

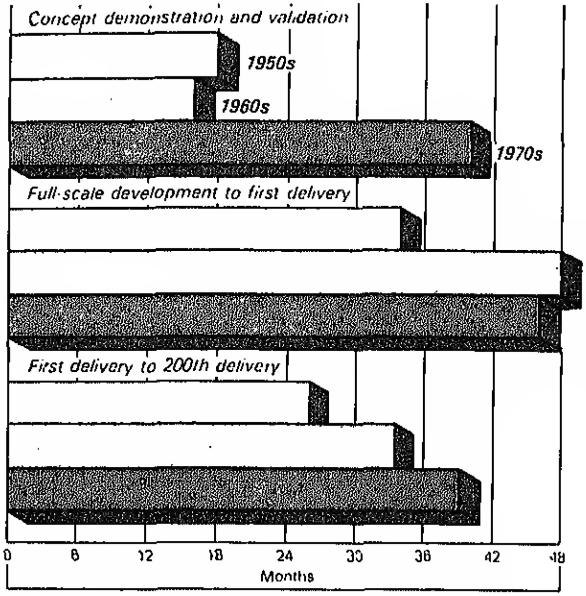


Sources: Program documents and *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s* (Santa Monica, CA: Rand Corporation, 1979).

An important premise of preplanned product improvement is that pursuing modest capability advances rather than new development programs can cut program costs and completion times. Moreover, that approach should reduce the risk of cost overrun and schedule slippage and thus translate into lower costs and shorter development times.[1] However, experience shows that caution is in order in accepting this premise as well. Although modification programs cost less than new programs and are deployed earlier, they do not always decrease the risk of cost overruns and schedule slippage. As is clear from Figure 2, modification efforts have occasionally exhibited greater cost growth than new programs.

Review of earlier modification programs suggests that those more successful in the areas of cost, schedule, and performance exhibited consid-

[1] *Robert Perry, et al.* System Acquisition Strategies *(Santa*



Source: G.K. Smith and E.T. Friedman, *An Analysis of Weapon System Acquisition Intervals, Past and Present* (R-2605-DR&E/AF, November 1980)

erably different management approaches than less successful programs. The former avoided highly concurrent development and production, allocated sufficient time and resources to proof testing, and provided a centralized management organization. In short, they avoided the classic pitfalls of weapons development programs.

If preplanning involves risks of unrealized improvements, faces traditional cost and schedule risks if poorly conducted, and is simply unworkable in its purest form, what strategies will address the procurement challenges of the 1980s? Although

payoffs, however, and deserve more attention: increasing the use of hardware competition in the acquisition process and reducing the time spent prior to issuing the hardware development contract in the system acquisition process.

Comparison of four competitive programs—the A–10, F–16, UH–60, and AWACS—proved revealing. All four competitively developed programs exceeded performance goals on average, while a group of noncompetitive programs—the F–15, Aegis, Harpoon, AIM–9L, CAPTOR, and M–198—fell short of meeting all performance goals. The competitive programs also had less schedule slippage and considerably less cost growth than the noncompetitive group.[2]

Reducing fielding times is feasible, but cutting the growth of deployment time intervals has more to do with reducing the time prior to actual hardware development than with compressing the full-scale development phase of the acquisition process. The majority of the time interval growth in the past decades has been in the early stages of development; actual hardware development time—the period from full-scale development to first delivery—has remained fairly stable (see Figure 3). Indeed, hardware development time has remained about the same since the 1930s.

Obtaining weapon systems that are effective, on-time, and within constrained budgets will no doubt continue to be a top priority in the Defense Department. But as the evidence reviewed above suggests, preplanned product improvement by itself is not likely to enable DoD planners and acquisition managers to meet those goals. They might better turn their attention to a mix of other strategies rather than emphasizing preplanned product improvement. DMJ

FREDERICK P. BIERY is a member of the staff of The Analytic Science Corporation. He previously worked for the General Research Corporation and the Rand Corporation. Mr. Biery holds a bachelor's degree from the American University and a master's degree in business administration from the Wharton School, University of Pennsylvania.

---

[2] *The data for these comparisons were developed from various Selected Acquisition Reports. The performance, cost, and schedule goals reflect estimates made at the beginning of full-scale development; the achieved results are as of March 1978. Costs reflect total program cost adjusted to exclude inflation and quantity changes. Performance parameters were averaged for each program and were equally weighted. If the achieved performance results came within 10 percent, the goal was considered accomplished. For more detail on these calculations, see Edmund Dews, Giles K. Smith, et al.,* Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s *(Santa Monica, CA: Rand Corporation, October 1979), Report Number R–2516–DR&E.*

What *are* the incentives in incentive contracts?

By DAN C. BOGER,
CARL R. JONES,
and
KEVIN C. SONTHEIMER

Cost- and profit-sharing arrangements in procurement contracts can actually create an incentive for government and industry management to allow costs which result in subsequent cost growth.

Interest in making major changes in the defense procurement process is steadily burgeoning. Changes to date have ranged from the introduction of multiyear contracting to a renewed emphasis on competition among contractors. Such changes are deemed essential largely because the Department of Defense continues to experience significant problems in controlling the cost, schedule, and performance outcomes of its procurement contracts.

These problems can hardly be considered surprising or new. In the early 1960s, DoD reduced its reliance on fixed-price contracts and increased its use of incentive contracts because the then-prevailing contract forms and practices were not perceived to be providing contractors with sufficient reason to control their costs. Later modifications of the process, such as total-package procurement, represented further efforts to eradicate the same vexing problem.

Concurrent with these changes in institutional practices was an increase in the number of analytical studies on the pluses and minuses of various contract types. While the research community originally addressed the more general problem, it has since gradually focused its attention more narrowly on those problems posed by risk and the consequent issue of optimal risk-sharing. This body of literature has led to a greater understanding of the role of risk and uncertainty in contractual arrangements, but it has also neglected other equally im-

The approach suggested in this article treats as primary determinants of contract performance two such aspects of the contractual arrangement. The first and more fundamental aspect is that production contracts for major weapon systems (wherein most cost growth has been experienced) are usually not one-period, one-time arrangements, but rather are ongoing relationships with contractors who have a long history of performing government work. The corollary aspect is that there exist links between these ongoing relationships and the federal budgeting process, that is, budget appropriations are conditioned by budget requests, which in turn are conditioned by prior contract experience.[1]

Recognition of these two aspects of the contractual relationship underlies the alleged buy-in phenomenon. To claim that contractors buy in is to claim that they have a time horizon in making a decision on a proposed contract which encompasses more than a single contract. Furthermore, the buy-in claim implicitly recognizes differences among proposed costs, actual costs, and minimum or competitive costs for a given contract. It also recognizes the process by which the allegedly excessive proposed costs are validated within the overall acquisition process.

This article reports the results of the integration of the two aspects into a model of the government-supplier

[1] *For a qualitative evaluation of one of the links in this process, see N. S. Bryan and R. Clark, "Is Cost Growth Being*

contractual setting.[2] The current model, which extends previous work, includes the effects of both varying lot sizes during the production cycle and the learning curve phenomenon occurring during the production process.[3] The results indicate that current institutional arrangements such as cost- and profit-sharing create an incentive for government and industry management jointly to allow costs which result in subsequent cost growth.

Basic assumptions

In modeling the government-supplier relationship, there are three major elements: the supplier or contractor and that party's behavior, the government and its behavior, and the contract which codifies the relationship between the two.

The contractor's business objective is to maximize profit over several time periods into the future. This implies that the contractor evaluates alternatives based on the discounted present value of the long-run profit streams that result from a particular decision. Although there has been criticism of this decision criterion, recent research indicates that several other criteria are in fact equivalent to long-run profit maximization.[4]

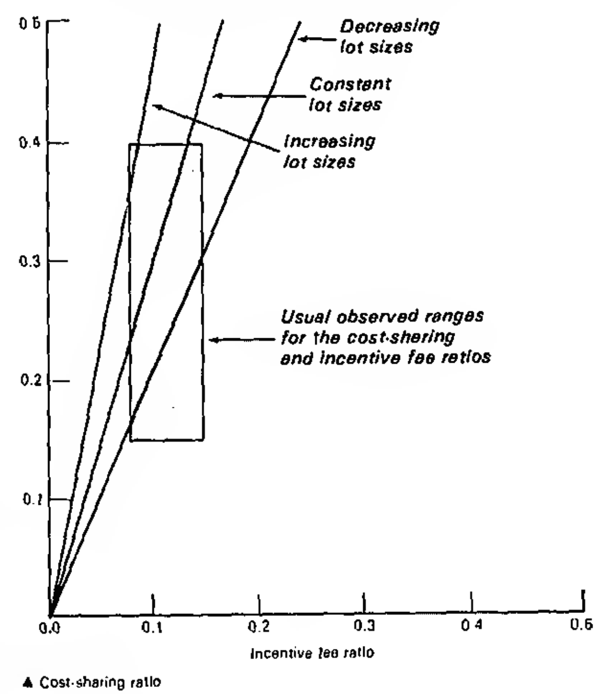
To facilitate the exposition, let us assume that the contractor is producing a single product. Because the contractor can be expected to learn a great deal in the doing can be treated as the labor efficiency effect.

The model treats the government as an amalgam of various bodies, agencies, and departments. Since no objective function is attributed to it, only its procedures and behavior are considered. Moreover, once decisions have been made, the procedures and behavior are considered public knowledge. This is particularly important in deriving the linkages discussed below.

In analyzing the government's behavior, one must understand the manner in which it budgets purchases. Funds are appropriated for a desired quantity of a particular product each year. While quantity of items and the money appropriated to buy them may vary from year to year, each is determined and fixed for a particular year.

The annual budget appropriation for a particular item is determined through calculations involving both the desired quantity of that item for that year and the item's historical unit costs. To facilitate the discussion, we have assumed that the purchase quantity is determined by such decisions as those made in the development of the Five Year Defense Plan. Historical unit costs are

Figure 1. An *ex ante* view of the contracting and budgeting process



[2] *A version of this paper which includes an analytical model is available from the authors.*

[3] *A selection of references from this literature is contained in Dan C. Boger, Carl R. Jones and Kevin C. Sontheimer, "An Analysis of the Incentives Present in Incentive Contracts," in* Proceedings of the 1982 Federal Acquisition Research Symposium, *U.S. Army Procurement Research Office, Ft. Lee, VA, May 1982.*

[4] *See H. E. Leland, "Alternative Long-Run Goals and the Theory of the Firm: Why Profit Maximization May Be a Better Assumption Than You Think," in P. T. Liu,* Dynamic Optimization and Mathematical Economics *(New York: Plenum Press, 1980).*

n competition is absent from this model. (An example this situation is the production phase of a major eapon system.) The chosen contractor can look forard to a sequence of yearly contracts that can extend r five-to-seven years or longer.

The contract itself, which is assumed to be of the neral incentive type, will provide for revenues to be id to the firm upon delivery of the required quantity the product. These revenues are determined by acal production costs, the proposed costs of production, id several incentive features. The primary incentive atures are those of the cost-sharing ratio and the inntive fee ratio. The cost-sharing ratio determines how e contractor and the government share cost overruns underruns; the incentive fee ratio determines the nount of the contract specifically set aside for profits the contractor.

nique model characteristics

It is hypothesized that there exists some minimum level.

Due to various factors such as the bureaucratic environment or managerial slack, however, observed costs have usually risen above this competitive level. The difference between competitive and observed costs is called convenience costs, which are a result of both the contractor and the government not having to enforce strict cost control. In fact, the relationship between the contractor and the government is typically not of the classic arms-length variety, but is more of a bilateral monopoly. It follows that government behavior can strongly influence the occurrence of convenience costs.

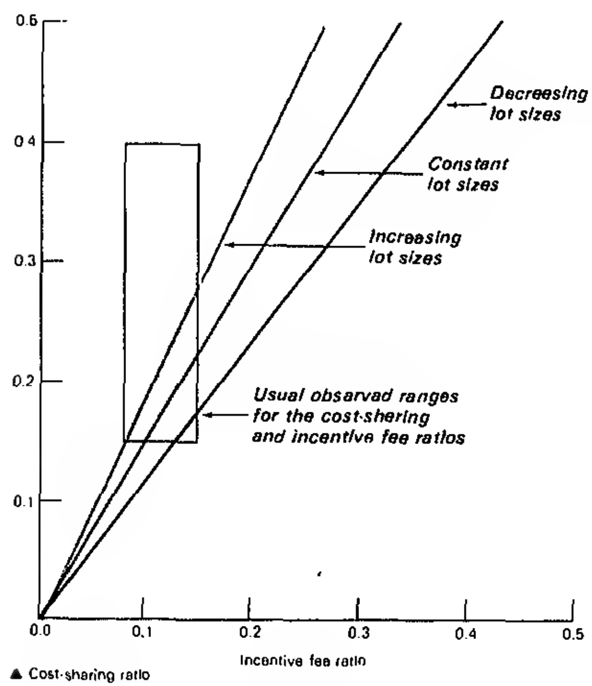
What causes convenience costs? One possible answer is that defense and industry managers often emphasize the technical and scientific aspects of a product to the apparent exclusion of the cost aspects. When this occurs, cost implications of alternative solutions to technical problems tend to be neglected. Pressures for these purely scientific or technical solutions exist on both sides of the contract relationship.

In addition to convenience costs, the linkages hypothesized are also important. The contractor views the sequence of contracts as being linked, since a decision to enter the first contract is a decision to enter all of the subsequent contracts. Additionally, a link is postulated between the budgeting process and the contractual relationship. This link is the proportion of requested funds which accrue to the contractor as a result of the initial contract negotiations.

This proportion, termed the budget parameter, must be examined prior to and subsequent to the budgeting process. The *ex post* value of the parameter depends upon how strongly the government wants or needs the product; this involves a combination of agency desires, presidential and congressional interest, and the political climate in which the defense budget was derived. However, the *ex ante* value of the budget parameter must be approximately unity.

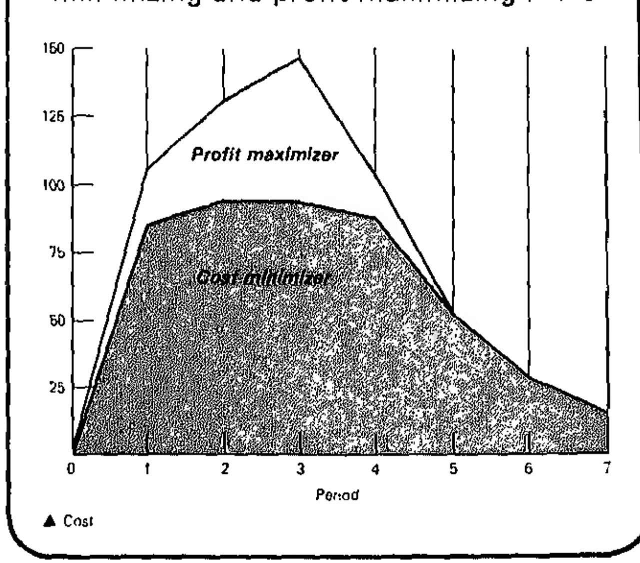
Viable contracting requires an implicit understanding between parties that allowable, recurring costs will be covered in subsequent contracts. Thus, the budget parameter, both *ex ante* and *ex post*, represents the transformation of current cost experience into subsequent contract appropriations.

Figure 2. An *ex post* view of the contracting and budgeting process



Model predictions

In a single period, an increase in convenience costs results in a decrease in the contractor's profits. How-



ever, in a multiple period environment, higher costs in early periods form a basis for the costs of all subsequent contracts. Consequently, it is potentially advantageous to the contractor to absorb convenience costs at the beginning of the contract sequence and later recoup this investment. This potential net profit is a function of the contract cost-sharing ratio, the incentive fee ratio, the contractor's internal discount rate, the labor efficiency effect, the quantity of products purchased in adjacent periods, and the proportion of the proposed budget accruing to the contractor.

Of primary concern in this analysis are the parameters which are explicitly part of the contract: the cost-sharing ratio and the incentive fee ratio. By postulating reasonable values for the remaining parameters, one can determine what combinations of these two principal parameters will result in a positive incentive for contractors to incur convenience costs.

A reasonable range for the firm's internal discount rate is 15 percent to 25 percent; for the cost-sharing ratio, 15 percent to 40 percent; and for the incentive fee, 8 percent to 15 percent. These are ranges which one would expect to encounter in practice.

Ex ante. To examine the interrelationships of the model's parameters, one may postulate alternative values for several of the parameters and determine the resultant effects upon incentives for convenience costs. For instance, one may consider the contracting and budgeting process in an *ex ante* or planning mode. In this case the contractor seeks to determine the value of participating in a sequence of contracts by focusing on the *ex ante* value of the budget parameter, which is one. An initial value for the learning parameter will be taken as 0.90; this indicates that, if lot sizes were to double from one year to the next, total costs would rise by only 90 percent. Finally, the firm's internal discount rate, which is really an inflation-adjusted, before-tax rate, will be initially set at a median value of 20 percent.

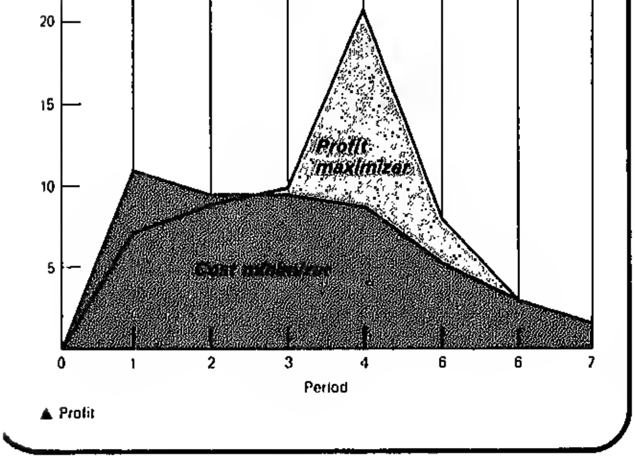
Reflecting these parameters, Figure 1 (p. 18) shows the relationship of the cost-sharing ratio and the incentive fee ratio for three alternative cases:

- Lot sizes constant over time.
- Lot sizes increasing by 10 percent from period to period.
- Lot sizes decreasing by 10 percent from period to period.

The points on each line represent those combinations of the cost-sharing and incentive fee ratios for which there are no incentives attached to costs. All points to the right of each line correspond to those combinations which result in a net incentive for the contractor to incur convenience costs. All points to the left of each line correspond to those combinations where there is an incentive to seek the competitive cost level. Clearly, there are far fewer combinations to the left of each line than to the right.

Moreover, an increase in the value of the learning parameter to a value closer to one (a case of no learning) will result in an increased incentive for the contractor to incur convenience costs. This is because a decrease in the amount of learning increases costs in all periods; thus, the contractor has a higher base of actual costs from which to invest his convenience costs. However, an increase in the value of the contractor's internal discount rate will result in a decreased incentive for the contractor to incur convenience costs. This is because the contractor is less willing to incur current costs which have a future return.

Ex post. This entire process may also be viewed in an *ex post* or realized budget mode. In this cas he



contractor seeks to determine the value of undertaking a specific contract by analyzing the *ex post* value of the budget parameter. Figure 2 (p. 19) shows alternative combinations of the cost-sharing and incentive fee ratios given that the budget parameter has an unusually low value of 0.80 and the same internal discount rate and learning parameter as in Figure 1.[5] Again, all combinations which occur to the right of the lines result in perverse incentives to the contractor.

A comparison of Figures 1 and 2 shows that a decrease in the budget parameter causes a reduction in the incentive to incur convenience costs. This is because a reduction in the budget parameter diminishes the linkage between prior costs and subsequent budgets, thereby decreasing the potential return to the contractor for incurring convenience costs.

A major conclusion of this analysis is that incentives change with varying lot sizes. As lot sizes increase, there is a relatively greater chance that a particular combination of the cost-sharing and incentive fee ratios will result in incentives for incurring convenience costs. This effect is so strong that if all of the parameters are set to the most unfavorable points of their ranges, a year-to-year increase of only slightly more than 60 percent will result in perverse incentives to the contractor. (These

[5] *Alternative values of the various parameters are explored for the case of no learning and constant lot sizing in Boger, Jones and Sontheimer,* op. cit. *Observed ranges of values for the cost incentive ratio, the incentive fee ratio, and the firm's internal discount rate indicated in that simpler model that the value of 0.80 for the budget parameter is unusually low.*

centive result.

An illustrative example

A detailed example will serve to clarify these general points and to illustrate several new ideas. Consider the following procurement pattern, where the numbers represent the purchase quantities in seven consecutive periods: 10, 15, 20, 25, 20, 15, and 10. Assume a competitive cost of $100 in the first period and a learning parameter of 0.90. (This information is sufficient to fully determine the competitive cost function for all seven periods.) Let the cost-sharing ratio be 0.20 and let the incentive fee ratio be 0.10; both of these are values actually found in practice. Let the contractor's proposed costs in the first period be $110, in which case the budget would be $121. Assume further that the upper limit on actual costs in any period is 12.5 percent above the proposed costs for that period and that there is a limit on cost incentive payments of 5 percent of proposed costs. Finally, assume that all costs are incurred in allowable categories, that the budget parameter is 1.0, and that the contractor's internal discount rate is 0.20.

Using these values, one can demonstrate that there exist incentives for the contractor to invest in convenience costs in the first three periods and incentives to attain competitive costs in the last four periods. The presence of these proper cost incentives in the last four periods is due solely to the declining lot sizes in these periods. The effects of these values on actual cost performance and the resulting profits can be illustrated with two cases: that of the cost-minimizing contractor and that of the profit-maximizing contractor.

Figure 3, which contrasts the discounted cost performance of the two cases, shows that the cost incentives are such that the profit-maximizing firm allows full expansion of the convenience costs in the first three periods. In period four, the profit maximizer begins to reduce its convenience costs and, solely in the interest of profits, starts the transition toward competitive costs. Notably, the profit maximizer does not move immediately to the competitive cost level because of the limit on cost incentive payments that can be made to the contractor in any one period. For the last three periods, the costs of the profit maximizer are indistinguishable from those of the cost minimizer.

In the fourth period of Figure 4, which profiles the

discounted profits of the two cases, the profit maximizer recoups the convenience costs built up in the first three periods. But because the limit on cost incentive payments is effective in the fourth period, some convenience costs remain for the profit maximizer in the fifth period. The remaining cost incentive payments received in the fifth period cause that period's profits to be larger for the profit maximizer than those for the cost minimizer even though competitive cost levels are realized for both in that period. The profits of the two cases are identical in the last two periods.

This example illustrates the potential for misinterpretation of profit-maximizing behavior. The actual costs incurred in the first three periods correspond to cost overruns. In the fourth period, the firm experiences a significant improvement in cost performance and achieves a significant cost underrun. A smaller cost underrun is experienced in period five and costs are on target in the last two periods. The improved cost performance in the latter periods could readily be misinterpreted as the beneficial results of exhortation, threats, and pressure exerted by DoD, the President, and the Congress during the cost overruns of the early periods. However, this improvement is only a response to the incentives presented by this particular combination of parameters—that is, as the contract circumstances warrant.

This example also illustrates that profits are actually higher in the first two periods for the cost minimizer than for the profit maximizer. This is because the profit maximizer is then engaged in investing in convenience costs which will be recouped. However, a single-minded concentration on profit levels alone could lead one to conclude erroneously that the cost minimizer is comparatively inefficient since the profit maximizer is earning a lower level of profits. It is even possible that exhortations to accept "low" profits could cause a contractor to transition from cost-minimizing behavior to profit-maximizing behavior. This points out the importance of viewing the contractual arrangement in its to-

combinations of the cost-sharing ratio and the incentive fee ratio can create incentives for cost growth despite the presence of cost-control incentives in a contract. The model also illustrates the sensitivity of cost incentives to changing lot sizes during production. In addition, incentives for cost growth can occur at easily observable values for the cost-sharing ratio, the incentive fee ratio, year-to-year changes in lot sizes, the contractor's internal discount rate, the labor efficiency factor, and the budget parameter.

Most importantly, this model indicates that at currently utilized values for the incentive fee ratio, the cost-sharing should be increased greatly to avoid incentives for the contractor to incur convenience costs. Although similar recommendations can be found elsewhere in incentive contracting literature, the present model is unique in that it offers a quantitative evaluation of the amount by which the cost-sharing ratio should be increased. DMJ

DAN C. BOGER is an assistant professor of economics in the Department of Administrative Sciences at the Naval Postgraduate School, Monterey, California. His areas of expertise include cost estimation, the economics of regulated industries, econometrics, and the acquisition process. Mr. Boger holds a bachelor's degree in management science from the University of Rochester, master's degrees in statistics and management science from the University of California, Berkeley, and the Naval Postgraduate School, respectively, and a doctorate in economics from Berkeley.

CARL R. JONES is a professor of economics and chairman of the Department of Administrative Sciences at the Naval Postgraduate School. He teaches and conducts research in the acquisition process, cost-benefit theory and practice, and information systems management. Mr. Jones holds a bachelor's degree in physics from Carnegie-Mellon University, a master's in business administration from the University of Southern California, and a doctorate in economics from Claremont Graduate School.

KEVIN C. SONTHEIMER is an associate professor of economics at the University of Pittsburgh. His teaching and research have focused on microeconomic theory, the economics of regulation, and the acquisition process. He holds a bachelor's degree in engineering from the University of Pittsburgh, a master's in economics from Pennsylvania State University, and a doctorate in economics from the University of Minnesota.

Property rights and the cost growth of weapon systems

By HAROLD J. BRUMM JR.

DoD policymakers seeking to curb weapon system cost growth should take into account factors motivating the economic behavior of personnel who manage those systems.

We need elucidation of the obvious more than we need investigation of the obscure.

—Oliver Wendell Holmes

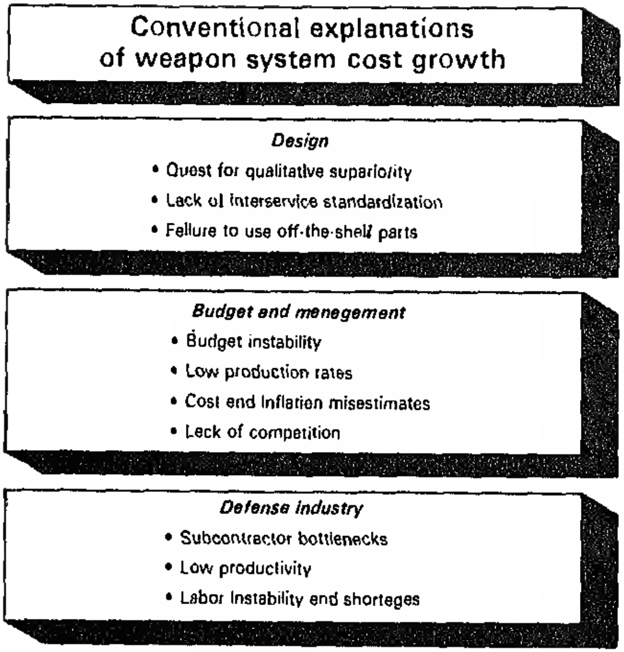
A widely known and disturbing fact is that the current generation of weapon systems is orders of magnitude more expensive than previous generations.* Moreover, this phenomenon is part of a continuing trend: over the last two decades the cost growth of military equipment and weapon systems, in *real* terms, has risen at an average annual rate of 6 percent.[1]

Various reasons have been offered for these escalating costs (see figure, p. 24).[2] There being nothing particularly mysterious about these pos-

* *The views expressed in this paper are strictly those of the author and do not necessarily represent any official position of the U.S. General Accounting Office.*

[1] *Leonard Sullivan Jr., "Correlating National Security and Defense Investment," in* From Weakness to Strength, *ed. W. Scott Thompson (San Francisco: Institute for Contemporary Studies, 1980), p. 343.*

[2] *Robert Foelber, "Cutting the High Cost of Weapons,"* Backgrounder, *No. 172, Heritage Foundation (March 16, 1982),*



sible sources of cost growth, proposals to mitigate their effects could be anticipated and indeed have been advanced over the years. Some of the latest are among the 32 initiatives issued by former Deputy Secretary of Defense Frank C. Carlucci in April 1981, which comprise the Acquisition Improvement Program of the Department of Defense. However, despite all such proposals and efforts to implement them, currently and in the past, the cost growth problem persists.

This conundrum has stimulated at least one writer to look in new directions for solutions. In his widely acclaimed book *National Defense,* James Fallows asserts that "the driving force behind these cost increases has been the pursuit of technical complexity." Fallows suspects that "the real reason . . . high technology is king has to do with the culture of procurement in the Pentagon." This culture, he further asserts, "draws the military toward new weapons *because* of their great cost, not in spite of it."[3] Although interesting, these assertions beg a question that Fallows never quite answers: what are the causal relationships between the economic incentives of DoD decisionmakers and the would, presumably, provide important insights into, if not outright solutions to, the problem of weapon system cost growth.

The present article argues that many of the "causes" conventionally attributed to the cost growth phenomenon are largely symptoms of the real problem, the property rights structure that exists in DoD. If this view is correct, the focus of efforts to curb weapon system cost growth should be expanded, if not redirected. The task would be to devise mechanisms that will make the self-interest of DoD decisionmakers, both military and civilian, more nearly coincident with the objective of minimizing the cost of maintaining an adequate national defense. Adequacy in this context is determined by the President and Congress.

In this article the term "property rights" refers to one's effective claims to rewards (positive or negative) as a result of one's actions.[4] Within any organization, property rights are sanctioned behavioral relations among the members of the organization; these rights derive from the scarce resources over which the organization has control. As such, the property rights system can be described as the set of economic and social relations that define the position of each member of an organization with respect to utilization of the resources available. The prevailing property rights structure within an organization, along with the individual's acquired and inherited human capital (intelligence, experience, and so forth), determines the set of opportunities—hence the trade-offs—confronting him or her.[5]

One hypothesis of this article is that individuals functioning within DoD have the same general motivations as other people; all respond to incentives. Thus if the perceived costs and benefits associated with any action change markedly, an individual's choices will also change. This view departs from that which ascribes a unique motivation to the DoD decisionmaker (for example, Fallows' *ad hominem* dichotomization of the professional officer corps into two groups: those with the culture of arms in

---

[4] *Roland N. McKean, "Property Rights Within Government*

ambitious[6]). The problem with such an assumption about human behavior is that it renders impossible any substantive predictions about the outcomes of objective circumstances, such as procurements of alternative weapon systems. One would have to make a psychological examination of any individual DoD decisionmaker before it would be possible to predict that person's behavior.

Given the assumption that DoD decisionmakers' choices, like those of all other individuals, are the outcome of egocentric cost-benefit analyses, understanding their behavior requires a knowledge of DoD's property rights structure and the opportunities Defense decisionmakers have for appropriating rewards. Significantly, to the extent that such appropriability is attentuated, inefficiencies will crop up in weapon system programs.[7]

The well-publicized case of the cost growth of the C-5A transport aircraft, albeit an extreme instance, illustrates this point. Even though several Pentagon officials evidently knew about this problem since at least November 1967, official admission of its existence was not forthcoming until Ernest Fitzgerald testified before a subcommittee of the Joint Economic Committee of Congress in November 1968.[8] This lack of candor can be attributed to the DoD bureaucrat's perception that, whatever benefits might accrue to society from divulging the C-5A cost overruns, he or she had little to gain personally from releasing the information. In fact, the DoD property rights structure had certain inherent disincentives to cost containment efforts. If these were not obvious already, they became readily apparent to other DoD personnel when Mr. Fitzgerald was fired in November 1969.

It is important to recognize that the inefficiency implicit in attenuated appropriability is not based on a misperception that isolated individuals, each with a different set of motives, make decisions (at least official ones) in DoD. Even if all DoD decisionmakers were motivated by the exact same objectives, it is unlikely that all would assign the same relative subjective values to different goals or to the different means available for attaining they preferred or regarded as more important. Group decisions are actually the outcome of decisions made by individuals whose self-interests vary, as do the values they assign to organizational goals and their perceptions of the best means to achieve those goals.[9]

A DoD decisionmaker, by definition, is a person who has the authority to exercise some discretion over the allocation of at least a portion of DoD's resources. The amount of discretion an individual possesses is one determinant of his or her set of opportunities. The weaker the correlation between the well-being of the individual (as he or she sees it) and the well-being of higher-level decisionmakers (as they see it), the more likely the individual is to increase the former at the expense of the latter. Higher-level decisionmakers realize this and therefore impose special constraints on the individual's choices—an unscheduled inspection of an aircraft squadron, for example, in order to check the validity of the commanding officer's operational readiness report. However, since detecting and policing infractions are not costless (time and effort are not free goods), each decisionmaker has opportunities to divert resources to the service of his or her own self-interest, possibly sacrificing some of the well-being of hierarchical superiors in the process.[10]

The hypothesis of self-interest maximization implies that an individual decisionmaker will try to expand the resources under his or her control beyond the quantity that higher-level decisionmakers deem optimal. By doing so, the decisionmaker increases his or her apparent contribution to the organization's output, thereby enhancing the likelihood that he or she will receive promotions and salary increases. And since individual performance in DoD cannot be evaluated by objective measures of productivity such as contribution to profitability, decisionmakers are in fact induced to offer other evidence of their worth to the organization in the form of visible tokens of accomplishment.[11]

This inducement may lead to outcomes which,

[6] *Fallows, p. 114.*

[7] *McKean, p. 180.*

[8] [illegible]

[9] *Louis De Alessi, "Implications of Property Rights for Government Investment Choices,"* American Economic Review, *March 1969, pp. 13-24.*

[10] [illegible]

ble for the acquisition of a particular weapon system has greater incentive to allow the contractor to put unnecessary "bells" and "whistles" on production units than would be the case in a competitive environment.

The property rights theory provides a plausible explanation for behavior which Fallows alleges to be characteristic of DoD decisionmakers. In a given procurement situation, he asserts, the more costly, more technologically complex weapon system usually will be chosen over its less costly, less technologically complex competitors.[12] As explained above, the property rights structure specifies norms of behavior with respect to resources that every member of an organization must either observe in his or her daily interactions with other members or otherwise bear the cost of nonobservance. That structure in DoD creates a real incentive to maximize the quantity of resources—people and dollars—under an individual's control. (As is readily observed, the fast track of promotion in the federal bureaucracy is "manager" rather than, say, "analyst"—the former manages resources, the latter does not.) Since the quantity of resources needed to acquire a more technologically complex system or subsystem almost always exceeds that for its less technologically complex counterpart, the former usually costs more to acquire.[13] Thus the incentive to maximize the quantity of resources managed leads to selection of the most costly, technologically complex piece of military hardware.

The F–16 aircraft, according to Fallows, provides an example of such "gold-plating."[14] Originally designed as a lightweight, low-cost fighter aircraft with a local battlefield air superiority mission, the F–16 underwent some not-so-subtle changes shortly after going into full-scale engineering development. What went into that development phase as an austere, single-mission fighter aircraft came out as an expensive, multiple-mission features into the F–16 to accommodate future technological enhancements, thereby transforming it into an even more expensive weapon system.[15]

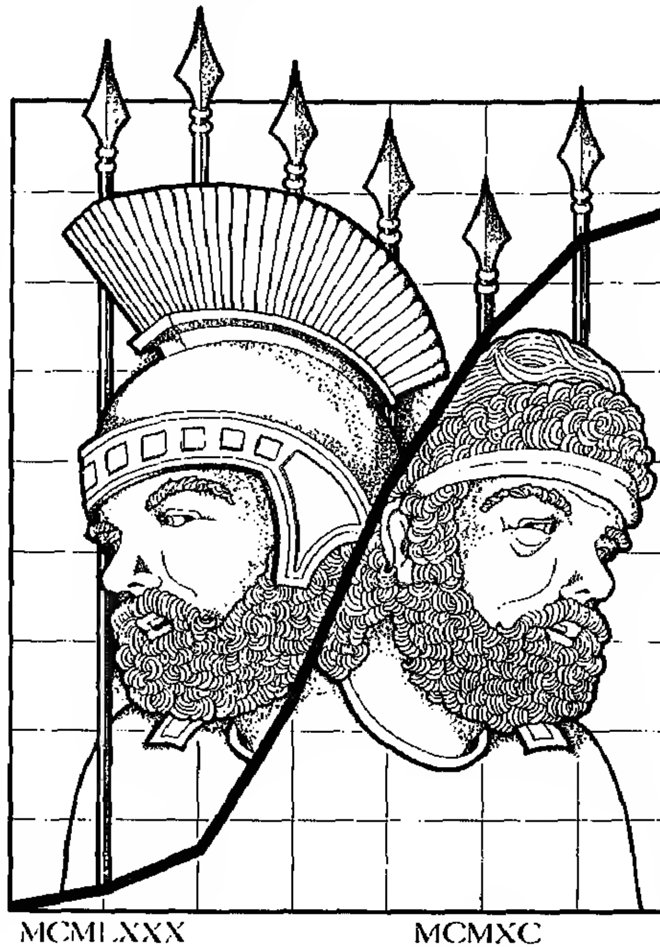


ILLUSTRATION BY SAUNDRA SIMPSON

Since greater technological complexity invariably increases a weapon's unit cost, some have attributed this additional cost to technological complexity *per se*, ignoring the incentives that induced the choice of the more technologically complex weapon system in the first place.[16] Yet such perverse incentive effects are a direct consequence of

[12] *Fallows, pp. 37–38.*

[13] *Franklin C. Spinney, "Defense Facts of Life," Department of Defense, December 5, 1980.*

[14] *The level of command at which Fallows directs his criticism in this particular instance is higher than the program manager, however. See Fallows, pp. 95–106.*

[15] *General Accounting Office,* The F-16 Program: Progress, Concerns, and Uncertainties *(Washington, DC: Government Printing Office, 1981).*

[16] *For example, see William D. White,* U.S. Tactical Air Power *(Washington, DC: Brookings Institution, 1974), pp. 49–5*

ary's "can do" philosophy does not easily accom-
.odate a program manager who reports that his r her weapon system "cannot do" or an officer ho reports that his or her command is not ready) perform its mission.[17]

The quest for visible tokens of accomplishment .kes the form not only of procuring more tech-ɔlogically complex weapons but also of trying to :ccelerate their introduction into the inventory. he Army's M-1 tank is an example. Although ıe tank continues to be plagued with propulsion roblems, the Army intends to buy 720 units this :ar anyway and eventually modify those units to ɔrrect existing defects. The service has opted for ıis course rather than delay the procurement until ıe requisite engineering fixes have been deter-ıined.[18]

The services' up-or-out promotion system, cou-led with the small likelihood of an officer ever ttaining flag rank, exacerbates the situation. Early ı their "first careers" as military officers, individ-als must begin planning for their "second ca-:ers" in the civilian sector following retirement 'om the armed services, which usually occurs in ıeir early forties—not the most propitious age at 'hich to make a career change. Thus for the officer ssigned a tour of duty in procurement manage-ıent, the prevailing property rights structure in)oD does not encourage taking a strong hand in realize that post-retirement "positions are offered to officers who have demonstrated their appreciation for industry's particular problems and commitments."[19]

Considerations such as these argue for a substantial overhaul of the current property rights structure in DoD. Some recommendations already proposed include:

- Replacement of the up-or-out promotion system with one that encourages commitment to a term of military service that exceeds the 20 years now typically served.[20]
- Establishment of an agency, possibly outside of DoD and independent of the research and development bureaucracy that promotes new weapons, to test and certify new technologies as mission-capable before they can be approved for procurement.[21]
- Introduction of interagency design competition within a given military department to avoid letting one particular development center enjoy a bureaucratic monopoly on a weapon system.[22]

Of course, these proposals far from exhaust all possibilities for improvement. They merely suggest what might be done to alter the property rights structure confronting players on the demand side of the weapon system acquisition arena.[23]

In the preface to his 1936 classic *The General Theory of Employment, Interest, and Money*, J. M. Keynes wrote: "The ideas which are here expressed so laboriously are extremely simple and should be obvious."[24] The general observations made in this article would seem obvious enough, too. However, the record to date suggests that they have not been given enough attention. It further suggests that, unless reconfigured, the property rights structure in DoD will continue to generate perverse incentive effects that will thwart policy directives otherwise designed to limit weapon system cost growth. DMJ

[17] *Cf. Fallows,* National Defense, *p. 64; Thomas H. Etzold,*)efense or Delusion? *(New York: Harper & Row, 1982), p. 13; and William V. Kennedy, "Honor Unbound,"* Washing-ɔn Post, *December 30, 1982, p. A19.*

[18] *U.S. General Accounting Office,* Large Scale Production f the M-1 Tank Should Be Delayed Until Its Power Train ; Made Durable *(Washington, DC: Government Printing Of-'ce, 1981).*

[19] *J. Ronald Fox,* Arming America *(Cambridge, MA: Har-ard University Press, 1974), p. 461.*

[20] *Martin Binkin and Irene Kyriakopoulos,* Youth or Ex-erience? *(Washington, DC: Brookings Institution, 1979), p. 7.*

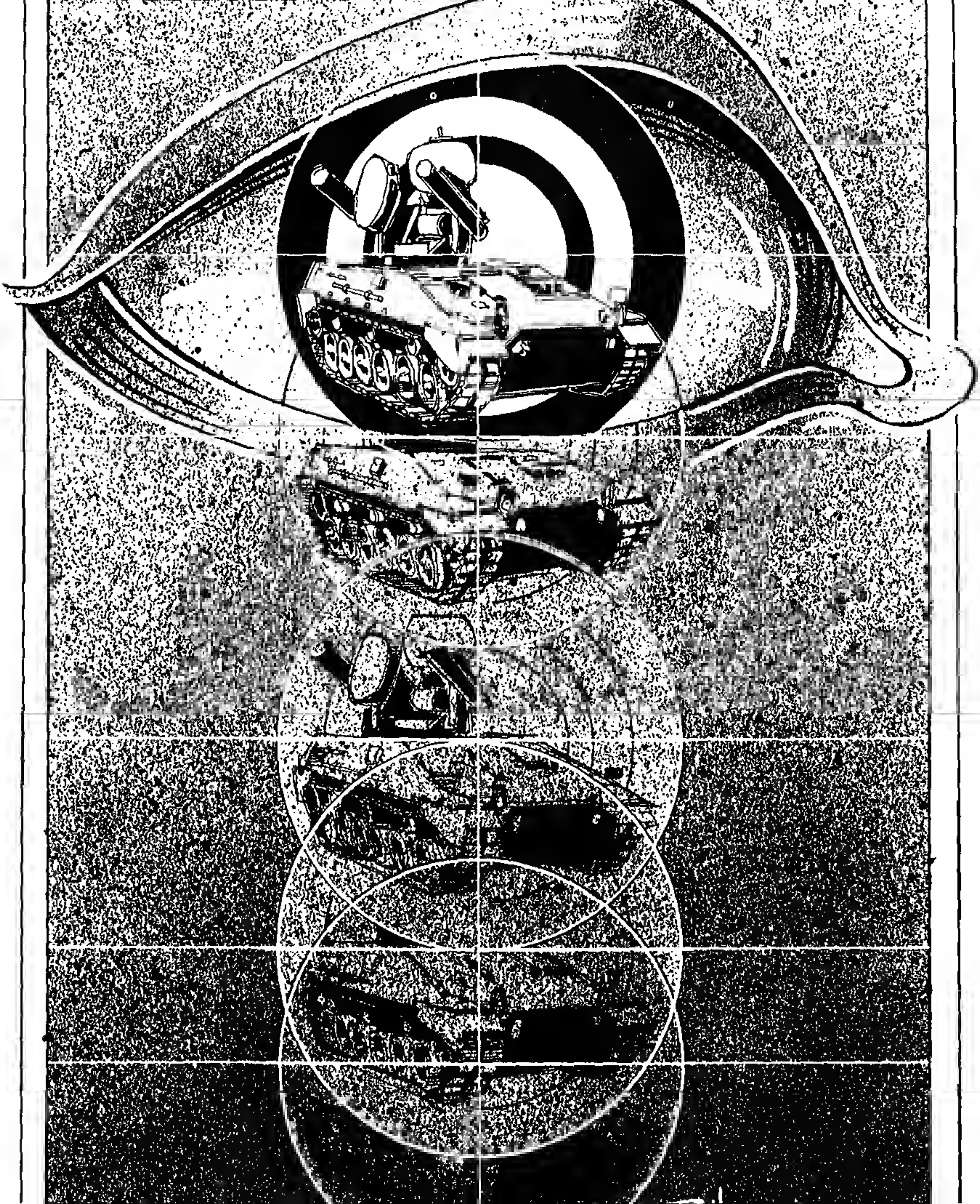
[21] *Fallows, p. 174.*

[22] *Fallows, p. 175.*

[23] *Other suggestions, including some germane to the supply ide of the military hardware arena, can be found in Fox,* \rming America, *pp. 449–478. Also see Dina Rasor, "Fight-ng with Failures,"* Reason, *April 1982, pp. 19–28.*

[24] *J. M. Keynes,* The General Theory of Employment... [cut off]

HAROLD J. BRUMM JR. is an economist with the U.S. General Accounting Office. Previously, he served as an economist with the Institute for Defense Analyses and with the Naval Material Command. Mr. Brumm holds a doctorate from the Claremont Graduate School.



A clear, simple guide to weapon system troubleshooting

By BARRY S. COSSEL and STEPHEN H. WATERS

As the services face a decline in the number of highly skilled personnel able to maintain sophisticated weapon systems, improved troubleshooting techniques can help reduce system downtime.

Sophisticated weapon systems are only effective when they are fully operational. Keeping system downtime to a minimum, therefore, is vital but increasingly difficult as weapons become more complex and competent maintenance technicians continue to be in short supply. In working on the U.S. Roland program, logistics engineers at Boeing were able to devise a troubleshooting method that addresses these problems. It is quick, relatively simple to use, and cost-effective when measured against comparable systems. This article describes that method, which is adaptable to other weapons systems as well.

When a system fails to operate properly, maintenance technicians usually troubleshoot the system to determine what is wrong, replace the faulty component, and then verify that the system operates properly. All too often, however, the process is not a smooth one. Frequently, the technician does not know where to begin troubleshooting or may not be able to understand the troubleshooting data. Sometimes he or she replaces the wrong component, uses complex, time-consuming test equipment and methods that are not really needed, or simply spends excessive time troubleshooting. Underlying all these problems is poor troubleshooting data; consequently, experienced, highly personnel of this caliber are becoming increasingly scarce.

Throughout the late 1970s, the average educational level of recruits was below that of earlier draftees, while at the same time large numbers of experienced personnel were leaving the military. In addition, lower birthrates have caused a decline in the pool of young men available for military service;[1] as a result, the military may need to attract one of every three eligible men to meet the next decade's manpower goals.[2]

The military has been trying to cope with this situation in part by improving and simplifying technical data. A restructuring of data is needed if technicians with low skill levels or limited system knowledge are to maintain complex systems without acquiring extensive analytical or system training. The Army's Technical Manual Writing Handbook reflects this straightforward approach to developing troubleshooting data by dividing it into three basic areas: fault discovery, entry to troubleshooting data, and troubleshooting accomplishment. The guidelines emphasize that such data must

---

[1] *Robert L. Goldich, "Military Manpower Policy and the All-Volunteer Force," Issue Brief 77032, The Library of Congress, Washington, DC, April 4, 1977 (updated July 7, 1980), pp. 4–6.*

tually to isolate a malfunction. It suggests a pyramid approach that starts at a general level and works down to details. Known as the modified half-split approach, this technique isolates a fault to half of the remaining system at a time until the final half is an individual, system-replaceable part. The writing guide also states that technical experience, turn-around requirements, ease of testing, test time, component reliability, user environment, and test equipment availability and requirements must be considered in developing troubleshooting data.

A new approach

Review of the U.S. Roland program to see if it complied with the Army's technical manual indicated that the program's troubleshooting data was incompatible with handbook requirements. To meet these requirements, Boeing developed a new approach to troubleshooting which combines several existing methods and offers a number of advantages.

The approach places all system troubleshooting data in one technical manual so that a technician does not have to decide which manual to use. Since systems operators report most faults, a separate chapter of the manual treats each operator function. Each chapter sequentially lists every visual or auditory event that occurs during successful completion of the function. If a fault develops, one of these events does not occur. Therefore, every visual or auditory event of every function is a separate starting point for a technician to begin troubleshooting. The detailed procedures are set forth in a series of yes-or-no questions which follow the pyramid approach referred to above and lead the technician either to replacing a specific component or to initiating automated testing.

Although the format is important, troubleshooting data are only as good as their supporting analyses. To create a disciplined methodology from are not only the basis for developing the troubleshooting data but are also a detailed record of the analysis performed.

Typically, troubleshooting starts with an operator who notes a fault and then reports that fault to maintenance. The maintenance technician refers to the troubleshooting guide and then repeats the operator function, noting the first visual or auditory event that does not occur. He or she next locates the specific troubleshooting procedures keyed to that event and answers the yes-or-no questions until the procedure directs the technician to replace a specific component or to conduct automated testing.

On the U.S. Roland program, the system schematics and wire list data closely support this troubleshooting approach. Restructuring of system schematics resulted in function-type schematics correlated with the functions in the troubleshooting manual, and wire list data are organized by signal name as listed on the schematics. Also included in the wire list data are the primary functions using the signal and the signal level. These changes, together with the troubleshooting manual, provide the U.S. Roland program with a cohesive set of technical data for troubleshooting and analyzing the operation of the system efficiently and effectively.

Functional dependency charts

The first step in preparing troubleshooting data is developing the functional dependency chart referred to above. This document, adapted from the maintenance dependency chart, represents the interdependencies of all visual, auditory, and key testable events that occur when the system accomplishes an operator-initiated function.[3] It also encompasses all replaceable components which must

[3] *Military Specification MIL-M-38799 (USAF), "Manuals, Technical: Schematic Block Diagrams (SBD) and Maintenance Dependency Charts (MDC)," August 15, 1971.*

of test points, replaceable components, lights, switches, and key items relevant to the function being analyzed. These entries are coded to identify initial states of switches, lights, test points, and other components; peculiar component data; and the location of component replacement procedures.

The body of the chart contains dependency lines which represent the signal flow through the equipment necessary for the function to be completed. Each dependency line ends in an event which is coded to identify the type of event or the value to be measured at the test point. A dependency symbol indicates that the event on the line is dependent on the occurrence of a previous event. Yet another symbol tells the technician that a replaceable component must function properly for the event on that line to occur. Other codes are used for switches, valves, and the like.

Preparing this chart is time-consuming and requires overall system knowledge as well as a set of integrated system schematics. In its finished form, the chart provides the analysis needed to prepare troubleshooting. Only when a complete roster of a system's functional dependencies are shown on the chart can they be presented as an integral part of the troubleshooting data. As a troubleshooting guide with supporting procedures, the chart eliminates the burdensome analysis that a maintenance person might normally have to perform.

A principal benefit of this troubleshooting approach is that it allows technicians at all skill levels and with varying degrees of system knowledge to rapidly troubleshoot a complex system without extensive training.

Although the functional dependency chart is de-

the writer to do a thorough, detailed analysis. Since the writer's depth of analysis is recorded on the chart, spot checks by a supervisor or the procuring activity will quickly detect an inadequate analysis. This feature solves a problem associated with traditional troubleshooting by eliminating uncertainty over whether the troubleshooting represents a thorough analysis or a last-minute rush.

Additionally, dependency chart analysis eases the task of incorporating changes in system design or maintenance concepts into the troubleshooting data. Finally, these charts have possible applications in the areas of system training and failure mode and effects analysis.

Troubleshooting guide

Each guide provides the data needed to begin troubleshooting a specific operator function and consists of two parts, introductory data and the actual troubleshooting guide. The four basic parts of the introductory data are:

- Initial function requirements.
- Initial troubleshooting requirements.
- Equipment requirements.
- General safety precautions.

Initial function requirements alert a technician to any conditions that must exist before a function can be performed. The initial troubleshooting requirements give information necessary to set up for troubleshooting, while the list of equipment requirements tells the technician what tools and materials are necessary to troubleshoot the function. General safety precautions are those safeguards required before or during the troubleshooting.

The troubleshooting guide is a tabular, chronological listing of all visual and auditory events shown on the dependency chart (see Figure 1, p. 32). A page number refers the user to each detailed troubleshooting procedure. A maintenance technician might use the troubleshooting guide as follows. Before assuming that a fault exists, the technician verifies that the initial function requirements were met. The technician then notes the initial troubleshooting requirements and general safety precautions, obtains the required equipment, and

change mode again (TM 9-1425-525-10) and verify that the events occur in order. Determine the first event that did not occur and then refer to troubleshooting procedure on page indicated.

Order	Ready to engage mode events	Reference Page
	NOTE The following troubleshooting guide is for changing from the ready mode to engage mode. If failure occurred while changing from standby or surveillance, place fire unit in ready before trying to go to engage. When ready mode cannot be reached, refer to page 5-1.	
1.	Did E light begin flashing after MODE switch was set to E?	6-3
2.	Did optical sight door open?	6-3
3.	Could turret lock be heard going up?	6-4
4.	Did INTRLK light on BITE control panel go out and interlock window show a code 0?	6-5
5.	Is E light on steady?	6-5

repeats the function. The first time that an event listed in the troubleshooting guide does not occur, the technician refers to the page number listed across from that event for detailed troubleshooting procedures.

Troubleshooting procedures

The troubleshooting procedures are developed by assuming that each event on the functional dependency chart is the first event that does not occur. Knowing which events occurred correctly enables one to determine easily the associated component and circuitry that are functioning and, therefore, are not faulty. The structure of the functional dependency chart facilitates this task. By simply looking at the chart, one can quickly locate most of the checks or testing needed to isolate possible faults. The procedures reflect the basic assumptions that only a single fault exists and that all events listed in the troubleshooting guide prior to the event in question occurred correctly.

A technician begins actual troubleshooting by answering a series of yes-or-no questions (see Figure 2). If an answer is positive, the technician does the next step at the same indenture level. If an answer is negative, he or she proceeds to the first subindentured step. This procedure continues until the troubleshooting either directs the technician to replace a faulty component or references specific automated testing. The lowest echelon of maintenance personnel do all steps unless a step is coded for higher-level maintenance personnel.

These procedures enable an unskilled technician to diagnose a system failure as though he were highly skilled in using the complete system analyses found in dependency charts. Technicians need not have extensive system knowledge nor do they need dependency charts to locate system faults.

Since personnel at all skill levels will use these procedures, they provide detailed information on performing standard troubleshooting tasks and on locating equipment and test points. To avoid making the procedures confusing and cumbersome, most of this data is placed in a separate chapter, so that highly skilled personnel can use the procedures with a minimum of detail.

Advantages

A principal benefit of this troubleshooting approach is that it allows technicians at all skill levels and with varying degrees of system knowledge to rapidly troubleshoot a complex system without extensive training. Several other features make it a superior approach as well:

- Troubleshooting is based on a logical analysis of normal system operation rather than on a shopping list of possible faults.
- It makes maximum use of available system

5. E LIGHT IS NOT ON STEADY

a. Is SYS NG light on? If not:

Replace cabin signal junction box (UW).

b. Remove access panel from logic unit and set system failure override switch S4 to TR. Does E light continue to flash? If not:

(1) Is 15 vdc present between LWJ9 pins 34 and 116? If not:

Adjust optical sight door open switch (TL2) (TM 9-1425-625-20-2.) If switch cannot be adjusted, replace switch (TL2) (TM 9-1425-625-20-2).

(2) Replace logic unit (LW) J120 card (TM 9-1425-626-20-2).

c. Set switch S4 to center position.

d. Is 15 vdc present between LWJ9 pins 46 and 116? If not:

(1) Is 28 vdc present between LWJ10 pins 104 and 83? If not:

(a) Is 15 vdc present between LWJ11 pins 38 and 50? If not:

1 Is 15 vdc present between LWJ11 pins 54 and 50? If not:

Replace logic unit (LW) J120 card (TM 9-1425-625-20-2).

2 Replace logic unit (LW) J121 card (TM 9-1425-625-20-2).

(b) Replace logic unit (LW) J122 card (TM 9-1425-625-20-2).

(2) Replace command computer (DR) (TM 9-1426-625-20-2).

e. Is 16 vdc present between LWJ9 pins 95 and 116? If not:

DS/GS — Replace turret locked limit switch (SG7) (TM 9-1425-626-34-1).

f. Is 15 vdc present between LWJ9 pins 30 and 116 and between pins 31 and 116? If not:

Replace logic unit (LW) J120 card (TM 9-1425-625-20-2).

g. Replace cabin signal junction box (VW) J104 card.

indicators and information concerning what does and does not operate properly.

• Use of complex test equipment is limited to only those situations in which it is really required.

• A disciplined analysis of system operation is performed, documented, and the results incorporated in the troubleshooting data.

• The approach has a single, clearly defined starting place and is integrated, not fragmented by subsystems.

methods carried out to a comparable level of detail, the costs are approximately the same and the approach requires significantly fewer pages.

These advantages suggest that serious consideration should be given to using this troubleshooting approach both for newly procured systems and for existing systems on which efficient troubleshooting has been a problem.

Outlook

Boeing began developing this approach to troubleshooting in June 1979 in response to problems that the Army was facing with available troubleshooting data. The demonstration conducted for the Army and contractor personnel in December 1979 showed that quick, accurate troubleshooting is possible under this approach, even when using simulated faults that technicians were not familiar with. The Army authorized full development of the approach for use with the U.S. Roland program and has also released a draft technical manual. In early 1983, Army personnel will formally validate the troubleshooting data by locating unknown simulated faults and any real faults that might occur. DMJ

BARRY S. COSSEL is a logistics engineer on the U.S. Roland program for the Boeing Aerospace Company. He has seven years of varied logistics experience on Army and Air Force programs, primarily in technical publications. Mr. Cossel holds a bachelor's degree in engineering from the University of Arizona and a master's degree in business administration from City College, Seattle, Washington.

STEPHEN H. WATERS is a senior logistics engineer on the U.S. Roland program for the Boeing Aerospace Company. He has 14 years of experience in technical publications and has worked on Army, Navy, and Air Force programs. He also spent two years as a stock and commodity broker for Dean Witter & Company, Incorporated. He holds a bachelor's degree in engineering from the University of Arizona and a master's degree in business administration from City College, Seattle, Washington.

Performance-based monetary rewards can boost individual productivity

By E. CHANDLER SHUMATE,
STEVEN L. DOCKSTADER,
and
DELBERT M. NEBEKER

The Navy's experiments with a performance-contingent reward system at selected shipyards have shown remarkable potential for motivating the work force to achieve greater productivity.

The term "productivity improvement" is rapidly becoming ensconced in the lexicon of management as the single most desirable goal that a manager can achieve. Unfortunately, it can also prove to be one of the most elusive.

Productivity—the ratio of work output to resource input—can be enhanced through advances in technology, methods improvement, and increased employee motivation. Yet while advances in technology and methods improvement hold tremendous potential for producing a given product at less cost, maximum efficiency cannot be achieved without a highly motivated work force.

With this in mind, the Navy Personnel Research and Development Center began a series of studies in 1975 directed toward developing and implementing motivational techniques designed to increase worker productivity in applied settings. One such technique, a performance-contingent reward system, has led to long-term improvements in the productivity of key entry operators at the Long Beach Naval Shipyard and the Mare Island Naval Shipyard. This article describes the studies carried out at these two activities and the results that were achieved.[1]

A performance-contingent reward system is a management method that awards a monetary bonus to an individual or group for performance that exceeds standards. A basic assumption underlying the implementation of such a system is that employees are not performing at their full potential. The proposition is not that people are basically lazy and don't care about their work. Rather, the premise holds that many people simply do not know what their full potential is and that most work environments provide neither the direction nor the incentive required to develop that potential.

Given these assumptions, managers and supervisors must decide how to maximize the performance potential of their employees. One way is to adopt a philosophy that people will voluntarily improve their performance, sometimes dramatically, if only they perceive that the improvement will be followed by positive consequences, such as meaningful and systematic recognition, and not by negative consequences, such as higher job standards or jeopardized job security.

Critical questions

In designing a monetary reward system to improve productivity, three questions demand consideration: Who should receive a reward? How much money should be awarded? And how often should a reward be given?

Who should receive a reward? Typically, an organization rewards its best performer or a very small group of employees. The problem with such a system, how-

[1] *From S. L. Dockstader, D. M. Nebeker, J. Nocella, and E. C. Shumate,* Incentive Management Training: Use of Be-

How much money should be awarded? Determining the proper amount to reward an individual or group should be based, in part, upon the value of their performance to the organization. Using a "sharing rate" concept, a manager could base the amount of a reward on some percentage of actual savings to the organization. Although this approach is used in administering the Federal Beneficial Suggestions Program, it has not been systematically applied to performance awards until quite recently.[2]

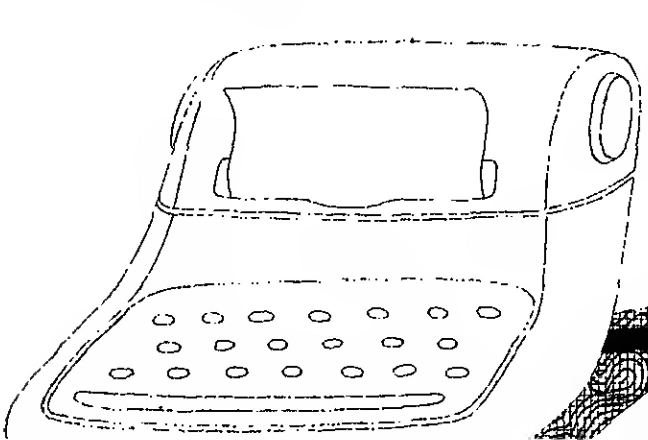
If a reward is to motivate, an employee must believe that the size of the reward merits increased personal performance. Currently, exact methods for determining optimal award levels have not been determined. However, one prominent industrial engineer has recommended a minimum sharing rate of 30 percent of the savings.[3] Since the reward is derived from money saved, the organization itself realizes a 70-percent savings (less program administration costs) and could justifiably increase the amount shared with the employee.

Managers must make the final decision, keeping in mind the best interests of both the organization and the employee. However, they should also consider the impact of the size of the sharing rate on other important issues, such as improving employee recruitment and selection, decreasing absenteeism and turnover, and reducing overtime, all of which traditionally entail high administrative costs.

---

[2] *E. C. Shumate, S. L. Dockstader, and D. M. Nebeker,* Performance Contingent Reward System: A Field Study of Effects on Worker Productivity, *Technical Report 78–20 (San Diego: Navy Personnel Research and Development Center, May 1978), AD-A055 796.*

[3] *M. Fein, "Wage Incentive Plans," in H. B. Maynard (ed.),* Industrial Engineering Handbook, *3rd edition (New York: McGraw-Hill, 1971).*



provide reward continuously (moment by moment) for above-standard performance. Although practical considerations, primarily administrative cost, render this unfeasible, one alternative would be to provide frequent, specific feedback that the employee could readily translate into a dollar value. Corollary logic suggests that the shorter the time between performance and positive feedback, the greater the effect upon performance.

Features of a reward system

A performance-contingent reward system is most adaptable to jobs that have the following characteristics:

- The work can be measured objectively.
- The work is recurring in nature.
- Satisfactory performance standards can be developed.
- The pace of the work is controlled by the individual or group.
- Performance can be directly associated with a specific individual or group.

While absolute compliance with these characteristics is not necessary (for example, only 70 percent of the work on a certain job may be objectively measurable) the probability of success is assumed to be directly related to the degree of compliance.

Work measurement system. An objective work measurement system provides the foundation for any effective productivity improvement program. Without objective measures, managers and supervisors can neither determine the productivity of their employees nor assess the results of any productivity enhancement program. An effective work measurement system requires clearly specified method statements for all measurable tasks, work measures that reflect appropriate job-related performance, performance standards that indicate how long it should take to perform the various tasks and an information system for collecting, integrating and reporting performance data. Work measures are useful only to the extent to which they relate to organizational objectives and are sensitive to changes in individual or group effort.

Recurring nature of work. The Navy Personnel Research and Development Center conducted a pilot study

e aforementioned job characteristics. The opera- task was to keypunch information contained on oximately 300 different source documents into the ard's computerized management information sys- The source documents were preprinted or hand- en forms that varied in length, format, color, and ility. The procedure used to enter each document clearly described in a manual available to all key operators. Documents arrived in batches from sites located throughout the shipyard and were d through a control section to the key entry sec-

or to the study, the operators picked up and logged own work. Some of them complained that certain iduals always picked up the simpler work and left nore difficult; understandably, they thought that would adversely affect their ratings under a per- ance-contingent reward system. The problem was ved by having the supervisors or their assistants bute and log the work, which had the added ad- age of allowing operators to remain at their work ons, thereby reducing nonproductive time. Expe- e gained at the shipyard and in subsequent studies ates that equitable distribution of work is critical. therwise sound program can fail or have its impact ficantly attenuated if employees perceive that the distribution is unfair.

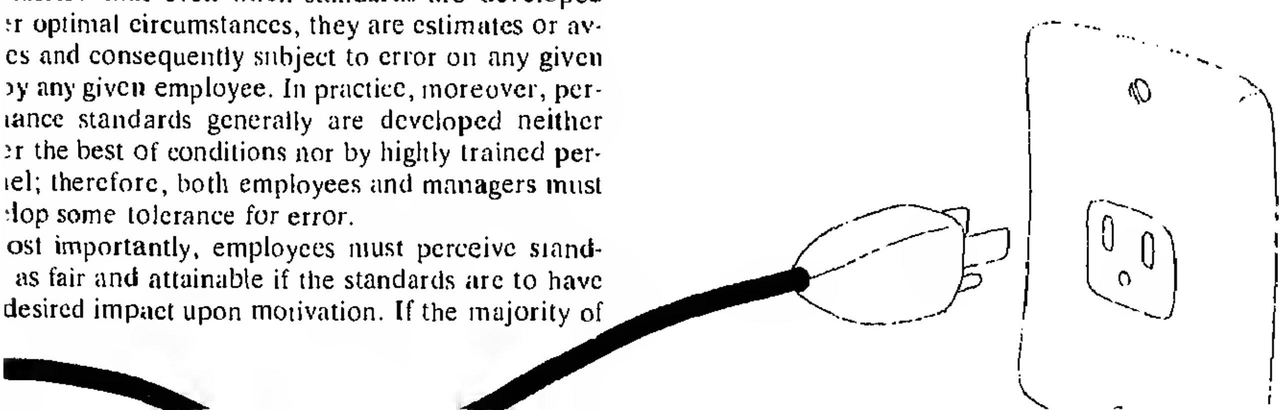
rformance standards. Another crucial element of a rd system is the determination of what work level be expected of an employee. Such expectations, *rally* referred to as performance standards, rep- nt a level of performance that warrants a "fair day's " Technically, a performance standard represents amount of time it should take an average, fully ed individual to perform a given task using stand- procedures under normal conditions. It should be hasized that even when standards are developed er optimal circumstances, they are estimates or av- es and consequently subject to error on any given by any given employee. In practice, moreover, per- nance standards generally are developed neither er the best of conditions nor by highly trained per- nel; therefore, both employees and managers must elop some tolerance for error.

ost importantly, employees must perceive stand- as fair and attainable if the standards are to have desired impact upon motivation. If the majority of

and Development Center researchers is to set or adjust standards so that at least the top 30 percent of the work force is performing at or slightly above standard prior to the introduction of a reward system. Based on the adage that "success breeds success," the rule suggests that the top performers will be motivated to perform at higher rates to earn more bonus money; in turn, the remainder of the work force will have reason to believe that they can also earn a bonus by improving their performance. Naturally, variations on this rule will depend upon local circumstances, such as a supervisor's knowledge that a majority of the work force is already performing at or near capacity.

At the Long Beach Naval Shipyard, performance standards were developed on the basis of the group's average rate for each procedure, expressed in keystrokes per hour. The degree of accuracy under an averaging method critically depends upon the reliability of the performance data;[4] key entry work was chosen for the pilot study in part because it yields highly reliable data. Rate categories were established by rank ordering the 300 procedures according to performance rates and dividing the rank order into five distinct ranges (such as 5,501–7,500 keystrokes per hour). Five categories were selected at Long Beach because the rank order produced that many fairly well-defined groupings; however, there are no established rules for determining the number of categories. Each procedure was placed into one of the categories and the value of the midpoint of that category became its standard. For example, procedures in the 5,501–7,500 category had a standard of 6,500 keystrokes per hour. Subsequent to the Long Beach

[4] *E. V. Grillo and C. J. Berg,* Work Measurement in the Office: A Guide to Office Cost Control *(New York: McGraw-Hill, 1959).*



Work measures. The primary work measure used at Long Beach was production efficiency, a summary statistic that describes a key entry operator's total productivity by combining two efficiency ratios, keystroke efficiency and productive time.

Keystroke efficiency is the ratio of an operator's actual performance rate relative to the performance standard. The performance rate may be variously expressed, depending upon what is *counted* (keystrokes, records, or batches) and the *time interval* of the count (minutes, hours, or days). Keystrokes per hour was the measure selected at Long Beach because operators were familiar with it. Thus, a key entry operator who exceeded a standard of 6,500 keystrokes per hour by 500 keystrokes would have a keystroke efficiency rate of 108 percent on that particular task.

Productive time is the ratio of the time actually spent working to the time assigned to work. On any job, no one is going to be productive 100 percent of the time. Industrial engineers generally use a 15-percent adjustment that allows for nonproductive activities (such as cleaning time and shift changes) and personal time (coffee breaks, social interchange, and so forth). Thus, an employee who worked 6.8 hours per day—8 hours less 15 percent—would achieve a productive time rate of 100 percent. To exceed the standard, an employee typically would have to reduce his or her personal time.

Reporting system. A reporting system for a performance-contingent reward system should be comprehensive enough to:

- Capture needed information only.
- Simplify methods of data collection.
- Report only information that is meaningful to the user.
- Automate as much as possible.

In the pilot study, a reporting system was developed that identified each operator by an assigned number and provided such information as the operator's shift, the procedures performed, performance rates on each procedure, and the time taken to complete each procedure. It also calculated keystroke efficiency, productive time, production efficiency, and incentive bonus earnings. The only data the supervisor had to enter manually was that indicating the amount of time each operator was assigned to a machine.

All key entry operators received a weekly report which past week and in the year-to-date. The supervisor received a report with the same information for each operator.

Payment system. The most significant feature of a performance-contingent reward system is its payment system. Of primary concern is correlating the reward with performance so that the amount of the bonus is directly proportional to the amount of work exceeding the performance standards.

This can be derived by multiplying four factors:

- The *production efficiency* rate, which is the product of keystroke efficiency and productive time. (For calculation purposes, this rate is expressed as the proportion exceeding standard performance, or 1.00).
- The *machine time*, which is the amount of time an operator was assigned to work at the machine.
- The *hourly wage*, defined as step 5 of the relevant grade level.
- The *sharing rate*, which is the percentage of money saved that is to be returned to the operators.

If, for example, a key entry operator had a production efficiency rate one week of 125 percent (1.25–1.00), worked at a machine for 35 hours, and earned \$3.97 per hour, that person's bonus for the week would be \$10.42, assuming a standard sharing rate of 30 percent ($0.25 \times 35 \times \$3.97 \times 0.30 = \$10.42$).

Delivery system. Finally, a reward system needs a procedure for delivering the reward expeditiously. The method chosen in the Long Beach study was to allow bonus money to accrue until it reached \$25 (this figure was chosen to reduce administrative costs). When it reached that amount, the operator could either withdraw all or part of the bonus or let it continue to accumulate. If payment was desired, the supervisor instituted administrative procedures through incentive awards channels. Depending upon the submission date, the operator received the money from the branch chief on the next payday, separate from the payroll check.

Replication of the pilot project

An important consideration in evaluating the impact of any new management technique is whether the results will generalize to other work settings. The basic concern is whether the results obtained in one study are unique to a specific group of people or a certain work situation rather than a direct effect of the new technique.

Mare Island Naval Shipyard. The key entry section at Mare Island was a good candidate for replication pri-

[5] *D. M. Nebeker and J. F. Nocella,* Keyprocessing Performance: A Method for Determining Operator Performance Standards, *Special Report 79-22 (San Diego: Navy Personnel Research and Development Center, June 1979).*

Officials from the Naval Sea Systems Command were sufficiently impressed with the results of the studies at the Long Beach and Mare Island Naval Shipyards that they asked the Navy Personnel Research and Development Center to help implement the system in the remaining shipyards. While staffing constraints precluded the Center's involvement at the same level of effort afforded Long Beach and Mare Island, researchers were able to develop a viable three-phase plan.

In phase 1, Center personnel visited the shipyards to talk with people who would be involved in the project and to describe the basic concept of the performance-contingent reward system. In phase 2, shipyard personnel attended an intensive two-day workshop at the Center in San Diego. Presentations addressed the theory and rationale underlying such elements of the reward system as feedback and recognition as well as such practical considerations as how to develop standards and a work measurement system. In phase 3, project managers implemented the system.

Four of six shipyards elected to implement the system. Of those four, three sites achieved improved performance. It was speculated that the failure to improve at the fourth site was due to an insufficient feedback mechanism, inadequate employee orientation, and an impending reduction-in-force.

The most promising outcome of the project is that it demonstrates that federal managers and supervisors, with a minimum of professional help, can develop, implement, and administer performance management systems that can significantly improve productivity. The Navy has since established a productivity management office responsible for developing a system to promulgate the transfer of performance technology to interested managers. That office and the Center are currently addressing that task.

marily because the work performed was essentially the same and the equipment was nearly identical. Mare Island differed in three important ways, however:

• Operators had a clearly established *daily production standard.*

• Operators were receiving *daily feedback* about their personal performance as well as the group's average performance.

• *Monetary bonuses* were issued *annually* to operators who exceeded the standard for at least 6 months, on the average; however, the same bonus of $150 was given to all operators exceeding the standard, regardless of differences in achievement.

Each of these primary differences is known to have a positive motivating effect. As such, it was felt that any improvement in productivity at Mare Island would not only validate the general concepts of the reward system, but would also provide some evidence of the system's capacity to improve productivity more than a system less contingent upon performance.

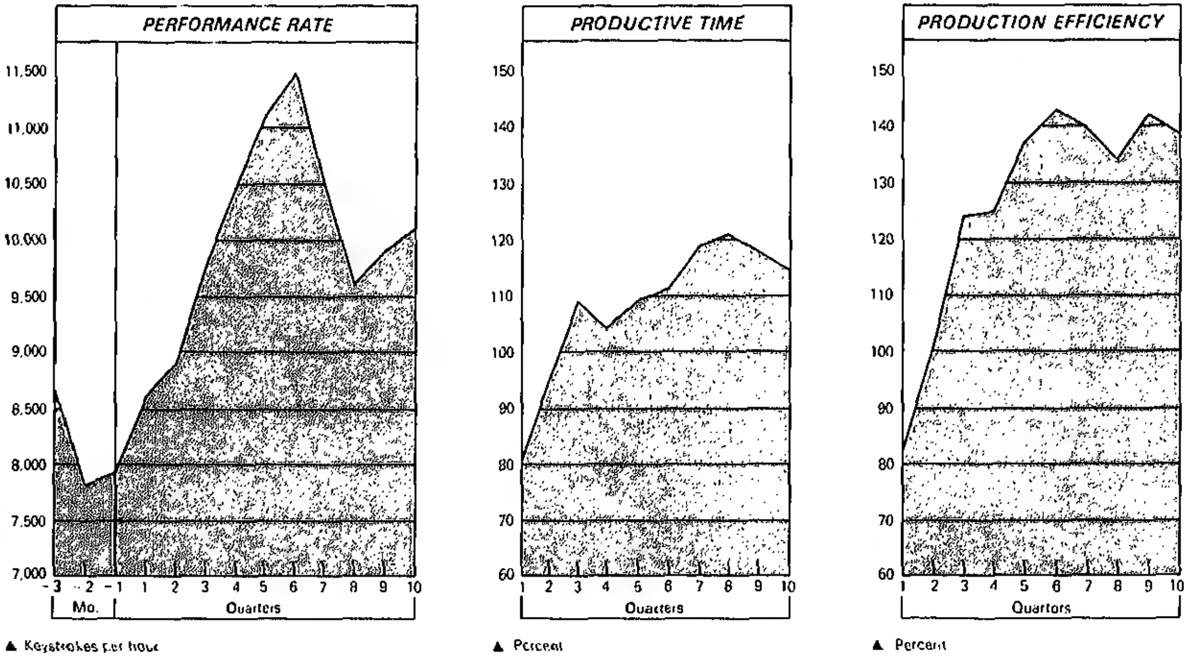
The reward system at Mare Island was patterned very much after the Long Beach program. The daily standard was replaced with performance standards for each procedure, and the production report was modified to accommodate the same productivity measures used at Long Beach. The only major difference between the two sites in terms of work measures was in the productive time standard: at Long Beach the standard was 6.4 hours: at Mare Island it was 7.1 hours.

Figures 1 and 2 (pp. 40 and 41) reflect the performance data at each site before the introduction of the performance-contingent reward system and for more than 2 years thereafter, at which point researchers stopped monitoring the program. Performance rate at the Long Beach Naval Shipyard immediately increased by 9 percent and for the most part remained above the pre-reward system level. The decrease in performance in the seventh and eighth quarters can be attributed to the loss of three high performers, two of whom left because of family moves and the other because of a better job opportunity. The significant improvement in total productivity is largely due to the increase in productive time; between the first and third quarters, for instance, productive time improved by 38 percent. *Most important from the management point of view, the reward system generated enough savings by the end of the first quarter to defray the total setup costs of the project.*[6]

The data from Mare Island invited some interesting speculation. While the reward system produced an immediate 11-percent increase in performance rates, those rates remained virtually unchanged for 27 months. Apparently, the reward system motivated the operators there to reach their maximum performance rates very quickly. At Long Beach, on the other hand, the im-

[6] *G. E. Bretton, S. L. Dockstader, D. M. Nebeker, and E. C. Shumate,* A Performance Contingent Reward System that Uses Economic Incentives: Preliminary Cost-effectiveness Analysis, *Technical Report 78-13 (San Diego: Navy Personnel Research and Development Center, February 1978). AD-A059 830.*

Significant improvements also occurred in the rate of productive time, where the 6.4-hour standard was bettered by 38 percent between the first and third quarters, and in production efficiency. Researchers theorized that the productivity improvements were a combined effect of operators learning how to work more efficiently and being motivated to do so.



provement to maximum performance was much more gradual. One might reasonably conclude that the improvement in performance at Long Beach involved both learning how to work at a higher rate and being motivated to do so, whereas the employees at Mare Island already knew how to perform at a high rate due to the feedback mechanism and the incentive system in operation there. The existing system had reached its capacity to increase performance; the new reward system simply tapped more performance potential.

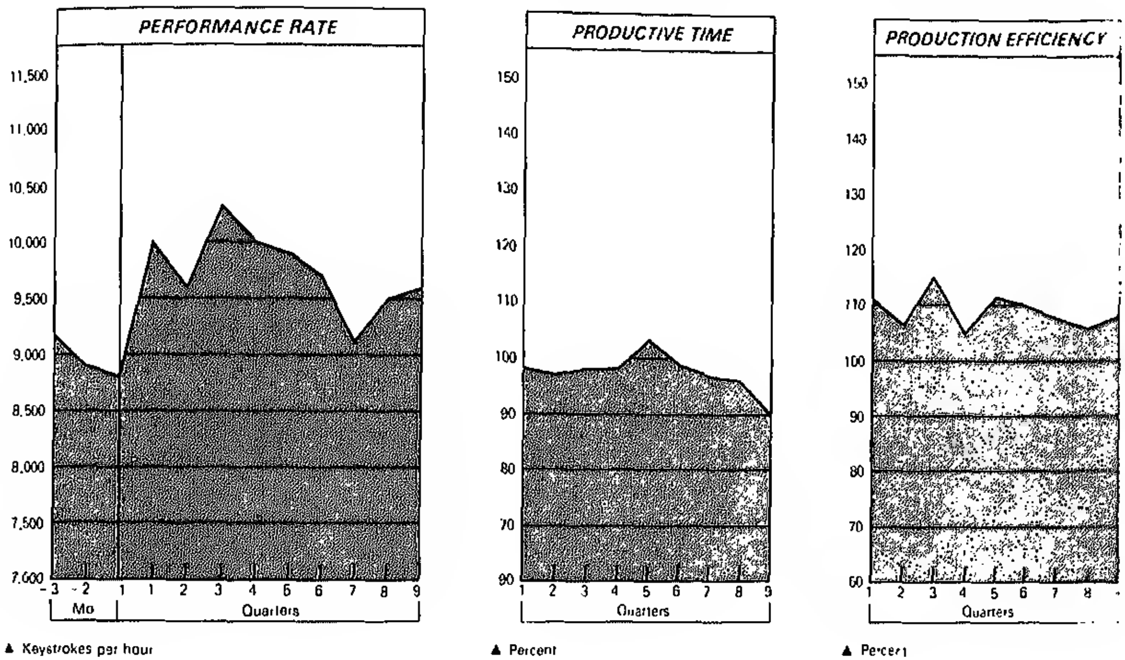
Finally, it should be noted that a direct comparison of performance measures between Long Beach and Mare Island is valid only for performance rate. Because managers at Mare Island decided to require their operators to work at their machines approximately 40 minutes a day longer than did managers of operators at Long Beach, it was very difficult for the Mare Island workers to surpass the 100-percent level for productive time. Nonetheless, improvement in performance at both sites was such that the effectiveness of each organization—as measured by cost per keystroke—was highly comparable 6 months after the programs were implemented.

It is encouraging to note the increasing awareness by government managers of the value of recognition in motivating employees. Attesting to this increased awareness are policies to integrate pay with performance and to decentralize the administration of the incentive awards program.

The favorable results of the studies at Long Beach and Mare Island Naval Shipyards have been instrumental in changing the incentive awards policies of both the Department of the Navy and the Office of Personnel Management. The Navy's new Productivity Improvement Awards Program and OPM's proposed Production Award System are based upon the same principles as those of the performance-contingent reward system.[7] In addition, the Defense Department has a proposed instruction under review that is directed towards im-

[7] *See, respectively, Appendix F to Civilian Personnel Instruction 451, July 1, 1982, and the proposed change to Chapter 451 of the Federal Personnel Manual.*

supervisors prior to the introduction of the performance-contingent reward system. Thus, although their performan... immediately increased by 11 percent under the new system, over time their rates of performance, productive time (their standar... was 7.1 hours), and production efficiency remained relatively unchanged. Researchers theorized that the existing reward syste... had reached its capacity to improve performance; the new system simply tapped more performance potential.



proving productivity not only through capital investment in new equipment and advanced technology but also through programs designed to increase work force motivation.[8] Specifically, the proposal states that managers and supervisors should, among other things, adapt trial applications of proven and promising motivation techniques to individual work situations. Successful programs would be documented, tailored to similar work situations, and adopted as widely as possible (see box on p. 39 for one example).

It is also worth noting that the performance-contingent reward system was designed as a *positive* program for performance improvement. Study participants were never told to increase their performance. If they chose to perform above standard, they received a bonus; if they chose not, there were no penalties other than those normally in force. Experience suggests that, because the proportion of poor performers is so small in most organizations and the potential gains are so great, managers need to accent the positive and minimize the ... ative. DMJ

[8] *Proposed DoD Instruction 5010.XX*, Work Force Motivation.

E. CHANDLER SHUMATE serves as the p... director of performance management systems at the N... Personnel Research and Development Center ... Diego, California. He received his doctorate in ex... mental psychology from the University of New M...

STEVEN L. DOCKSTADER serves as the p... director of industrial management and military pre... edness at the Navy Personnel Research and Develo... Center. He received his doctorate in experiment... chology from the University of Denver.

DELBERT M. NEBEKER is an associate pro... of management at San Diego State University. He ... serves as manager of the productivity and incentive m... urement facility at the Navy Personnel Research ... Development Center. He received his doctorate in ... ganizational psychology from the University of W... ington.

Sharing human intelligence through a computer network

By ROBERT J. KNEZ

Consultants Anonymous, a proposed organization of multidisciplinary subscribers to a time-shared computer system, could be an effective tool in retaining this country's preeminence in technological development.

In his book *The Third Wave,* Alvin Toffler wrote about the two great waves of change that the human race has undergone: the agricultural revolution, which occurred over thousands of years, and the industrial revolution, which took 300 years. Toffler also postulated a third wave, now under way, which will complete its sweep in only a few decades. The key to this third wave is the emergence of the computer and the impact of that phenomenon on society.

The premise of this article is that the third wave may be this nation's most effective tool for maintaining our technological advantage over potential adversaries.* While our leadership is presently taking steps to stem the ongoing transfer of technology—both legal and clandestine—to such countries, perhaps the best way to safeguard the balance of power is by simply staying ahead of the competition.

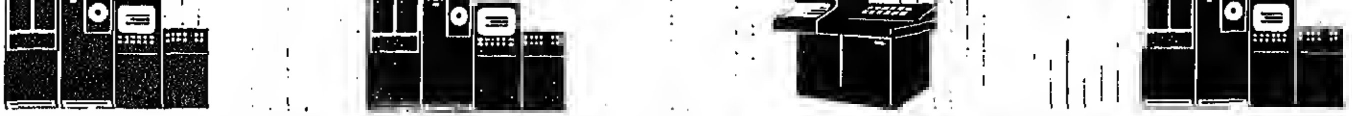
One way to do so is by promoting the pollination of ideas across subject disciplines via a time-shared computer network. Although previous implementations of such systems have been restricted to a small group of professionals working on prespecified, often esoteric problems, there is no practical reason for not making a time-shared system available to a much wider variety of military and civilian personnel for day-to-day use in problem-solving.

"Consultants Anonymous," the name used in this article to identify such a computer network, ideally would be implemented using an existing time-sharing system. Numerous automated information systems are currently providing such services as bibliographic search, technical information retrieval, and electronic mail; by making Consultants Anonymous part of such a system, a subscriber could readily switch from one service to another. Predictably, equipment acquisition could also be minimized in this way.

The basis for Consultants Anonymous is the Crawford Slip Method, developed by C. C. Crawford in 1925. The method derives from Crawford's practice of giving 3" × 5" slips of paper to an audience and asking them to provide their solutions to a precisely targeted problem. In effect, the method generates innovative thinking and captures unrecorded know-how while relieving the audience's inhibitions through anonymity. According to Crawford, the psychological benefits gained from combining brainpower include bolstering courage, subdividing large projects, gathering raw material for thought, adding fractions of know-how, structuring the composite, diagnosing problem situations, building consensus toward remedies, forecasting acceptance of remedies, and improving implementation.

As such, Consultants Anonymous would be particularly useful to managers who work in subject areas that are as yet largely undocumented and who analyze problems that are massive in scope. For example, a project planner might be faced with the task of verifying the completeness of an activities list and the sequence of execution before a project's cost can be estimated and a completion date projected. Activity lists can consist of hundreds of events, and omission of a single critical event can cause severe problems. But a community of multidisciplinary subscribers such as Con-

* *This article is adapted from Robert J. Knez,* Mutual Problem Solving Through Computer Time Sharing *(Carlisle Bar-*



and identify related activities that perhaps went unrecognized by the planner.

The variety of potential problems that the system could take on is virtually unlimited. These might include:

• What is the greatest security threat facing the U.S. in Asia today? (Addressed to military officials.)

• I am having difficulty in getting release 36 of Corporation Y's operating system to work. It will not allocate disk space properly on model Z disk drives. Has anyone else had a similar problem with this release? (Addressed to an association of computer users.)

• I am developing a PERT network for the design, development, and implementation of a new manufacturing process for widgets. Please recommend proper sequencing and identify any missing critical events from the following list. (Addressed to manufacturers and managers.)

Moreover, the simplicity of the Crawford Slip Method makes it an ideal choice for automation. No preplanning or formal gathering of a problem-solving group is necessary. A person with a problem to submit would key in the problem, identify the target audience, and specify a time or a number limit on responses. If there were responses, the submitter could ask to see them in chronological or alphabetical order, by discipline of the responder, by keyword, or in some other computer-compatible order. Meanwhile, the submitter might be informed that another submitter had requested similar assistance from subscribers in his or her professional discipline or association.

No submitter would be obliged to review and respond; however, submitters who had received helpful responses to their own problems would probably do so. Before signing off, the submitter could notify the system that one or more respondents had provided exceptionally useful solutions. Through a special construct called a "stroke," a thank-you note could be sent to the respondent and a permanent record made to reflect that person's contribution to the system.

Of course, the real value of such a system will be evident only when it is widely used. If it is not, it will rapidly approach complete disuse; but if it provides a useful service, the demand for that service should rise to mee th limits of the service. This in turn necessitates of Consultants Anonymous as only one node in a network of Consultants Anonymous systems.

Naturally, Consultants Anonymous must be easy to use. It must also be cost-effective in terms of its users' personal time, and the users must be able to recognize this advantage. It is important to assure people, particularly busy executives, that such a system can frequently be more effective than conventional face-to-face and telephone communications because of its easy accessibility to large audiences.

Still, human beings, the real resource in Consultants Anonymous, will not remain satisfied for long in an anonymous and unrewarded state. To satisfy the basic human need for recognition, Consultants Anonymous must contain some sort of status system. Perhaps titular degrees such as Associate, Expert, and Master could be bestowed based on the significance and frequency of the subscriber's contributions. As sufficient "strokes" were received, the contributor's degree status would be elevated. And if the system proved to be especially useful, monetary awards might also be considered.

To maintain the cohesiveness of the diverse users, Consultants Anonymous could publish a weekly or monthly video newsletter. This publication could publish letters from members, show examples of good problem submittals and responses, explain new system features, recognize members whose status has been elevated, and so forth. It could also serve as a vehicle for subscribers to express their feelings about the system's operation and to collect suggestions for improvements.

In this age of the "third wave," computer system applications such as Consultants Anonymous seem both inevitable and sensible. Corporations and nations that accept and learn to harness this wave of change will emerge or remain as leaders of industry and the world. If the United States is to maintain its technological leadership and thereby assure its economic stability, it must not shrink from this task of gathering intelligence and distributing it through the power of the computer.

DMJ

ROBERT J. KNEZ is director of automatic data-processing systems at the Defense Technical Information Center, Alexandria, Virginia. He was previously deputy director of data systems at the Defense Electronics Supply Center, Dayton, Ohio. A 1982 graduate of the U.S.

Event	Date	Place	Contact
Annual Symposium	Feb 18-19	Ogden, UT	Society of Logistics Engineers Attn: Dr. Robert Stein 303 Williams Avenue, Suite 922 Huntsville, AL 35801 (801) 626-6911
Logistics Planning and Management Seminar	Apr 5-7	Arlington, VA	
Basic: A Computer Language for Managers	Feb 21-23 Feb 23-25 Mar 1-3	Boston, MA Chicago, IL Atlanta, GA	American Management Associations 135 West 50th Street New York, NY 10020 (212) 586-8100
Improving Office Productivity: Analysis and Design Techniques for Manual Systems	Feb 28-Mar 3	New York, NY	
The Supervisor As A Member of Management	Feb 22-23 Feb 22-23 Feb 24-25	New York, NY San Francisco, CA Boston, MA	Practical Management Associates, Inc. 6910 Owensmouth Canoga Park, CA 91303 (213) 348-9101
Successful Middle Management	Feb 23-25 Mar 2-4	Austin, TX Chicago, IL	
Managing the Organization from the Top	Mar 10-11	Williamsburg, VA	
Using Small Computers in Government	Feb 28-Mar 1 Mar 14-15 Mar 21-22	Atlanta, GA Dallas, TX Washington, DC	U.S. Professional Development Institute Small Computer Seminars Department A B 12611 Davan Drive Silver Spring, MD 20904 (301) 622-5696
Developing Small Computer Applications in Government	Mar 2-3 Mar 16-17 Mar 23-24	Atlanta, GA Dallas, TX Washington, DC	
Project Scheduling Workshop	Feb 28-Mar 2	Berkeley, CA	Humphreys & Associates, Inc. 1300 Quail Street Newport Beach, CA 92660 (714) 955-2981
1983 SAE International Congress and Exposition—The Engineer: The Key to Productivity	Feb 28-Mar 4	Detroit, MI	SAE, Communications Division 400 Commonwealth Drive Warrendale, PA 15096 (412) 776-4841
Twenty-First Goddard Memorial Symposium: Space Applications at the Crossroads	Mar 24-25	Greenbelt, MD	American Astronautical Society 6060 Duke Street Alexandria, VA 22304 (703) 751-7721
Second Annual Logistics Planning & Management Seminar	Apr 5-7	Arlington, VA	Calculon Corporation Attn: Ira Katz 1301 Picard Drive